Technical Report CHL-97-22
December 1997

US Army Corps of Engineers
Waterways Experiment Station

Results of Monitoring Study of Agat Harbor, Guam

by *David D. McGehee, WES*
Stanley Boc, Pacific Ocean Division

Prepared for Headquarters, U.S. Army Corps of Engineers

Technical Report CHL-97-22
December 1997

Results of Monitoring Study of Agat Harbor, Guam

by David D. McGehee

U.S. Army Corps of Engineers
Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

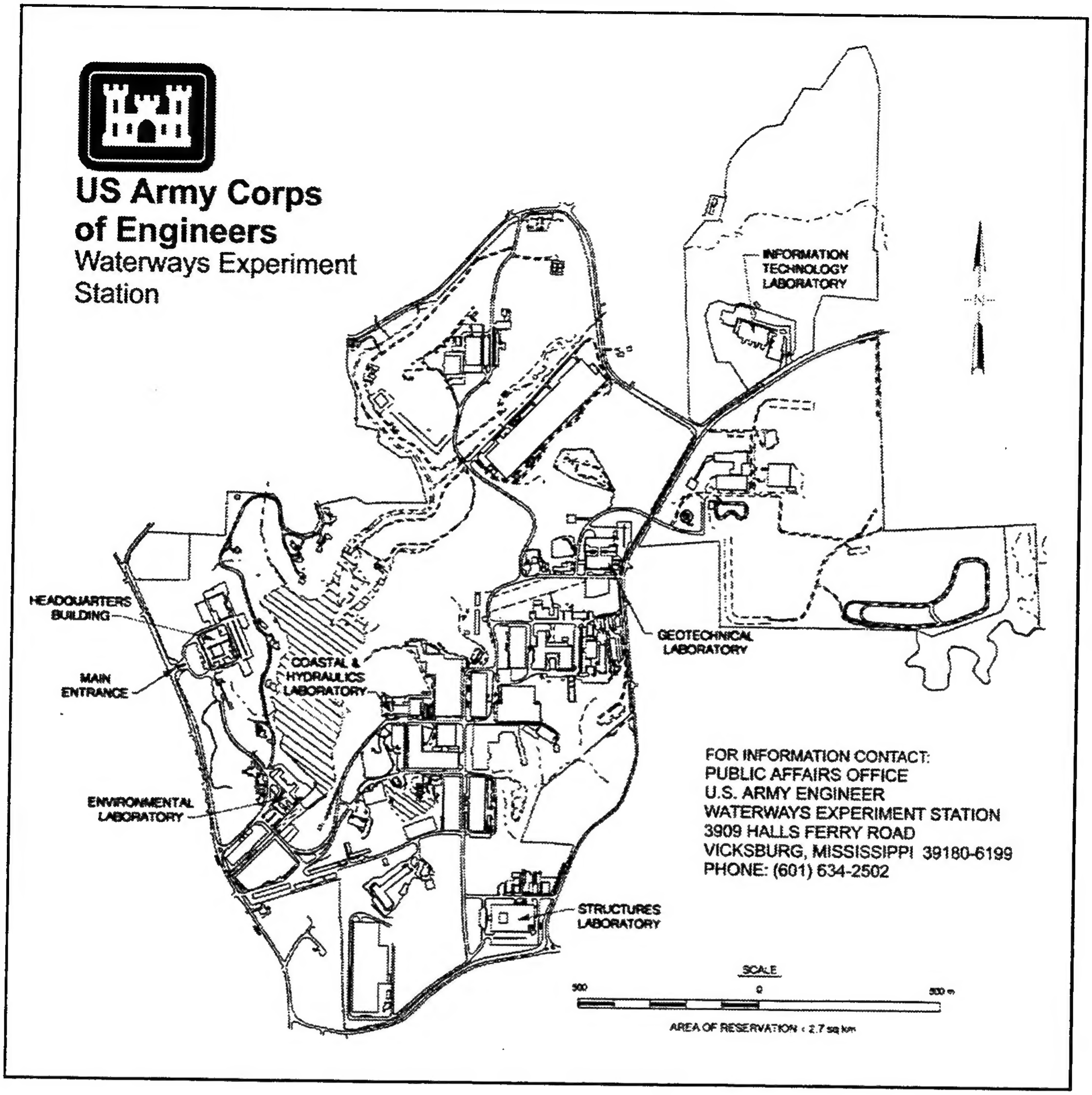
Stanley Boc

U.S. Army Engineer Division, Pacific Ocean
Bldg. 230
Fort Shafter, HI 96858-5440

Final report

Approved for public release; distribution is unlimited

Prepared for U.S. Army Corps of Engineers
Washington, DC 20314-1000



Waterways Experiment Station Cataloging-in-Publication Data

McGehee, David D.
Results of monitoring study of Agat Harbor, Guam / by David D. McGehee, Stanley Boc ; prepared for U.S. Army Corps of Engineers.
180 p. : ill. ; 28 cm. — (Technical report ; CHL-97-22)
Includes bibliographic references.
1. Breakwaters — Guam. 2. Harbors — Guam. 3. Ocean waves — Guam. 4. Water waves — Guam. 5. Agat Harbor (Guam) I. Boc, Stanley J. II. United States. Army. Corps of Engineers. III. U.S. Army Engineer Waterways Experiment Station. IV. Coastal and Hydraulics Laboratory (U.S. Army Engineer Waterways Experiment Station) V. Title. VI. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; CHL-97-22.
TA7 W34 no.CHL-97-22

Contents

Preface vi

Conversion Factors, Non-SI to SI Units of Measurement viii

1—Introduction 1

2—Project Description 2

- Site Description 2
- Design Criteria 3
- Design Methods 4

3—Monitoring Plan 7

- Objectives 7
- Monitoring Elements 8
- System Design 11
- Analysis and Sampling Plan 16
- System Installation 17
- The Unanticipated Monitoring Element 18

4—Monitoring Results 21

- Performance 21
- Results 27

5—Discussion 37

6—Conclusions 41

References 43

Appendix A: Work Description and Reports for Contracted Current Measurements A1

Appendix B: Performance Critique B1

Appendix C: Summary Statistics of Incident Wave Conditions C1

Appendix D: Measured Wave Data Plots D1

SF 298

List of Figures

Figure 1. Location and site map of Agat Harbor, Guam 3

Figure 2. Aerial view of southwestern coast of Guam 4

Figure 3. Agat Harbor channel under construction 5

Figure 4. Agat Harbor under construction 6

Figure 5. Idealized reef and sand beach profiles 7

Figure 6. Plan of nearshore gauge locations 10

Figure 7. Single point transducers housing and mount 13

Figure 8. Slope array transducers/electronics housing and mount 13

Figure 9. Data management scheme 15

Figure 10. Custom gauge deployment barge 18

Figure 11. Short-term pressure sensor deployment sites 20

Figure 12. Typhoon Omar, Guam, 28 August 1992 22

Figure 13. Data capture performance and offshore wave height, by year 23

Figure 14. Rose plot of incident wave conditions 28

Figure 15. Typhoon Russ; path and observations 29

Figure 16. Wave transformation; pressure time series 30

Figure 17. Energy spectra for sites 1B (a) and 2A, 2B, and 4A (b) on 10/16/92 @ 0600 hr 31

Figure 18. Energy spectra for sites 1B (a) and 4A (b) on 8/06/93 @ 1600 hr 32

Figure 19. Pressure time series at site 2-M for typhoons Omar and Brian 33

Figure 20. Breakwater surface 35

Figure 21. One-hour "blow-up" of oscillations at sites 2-M and 3-O, 25 October 36

Figure 22. Schematic representation of reef flat circulation/oscillation . . . 40

List of Tables

Table 1. Sampling and Analysis Scheme for Onshore System 16

Table 2. Summary of Reef Flat Wave Transmission Events 29

Table 3. Seiche Modes for a Rectangular Basin 38

Preface

This report was prepared by the U.S. Army Engineer Waterways Experiment Station (WES) Coastal and Hydraulics Laboratory (CHL), which was formed in October 1996 with the merger of the WES Coastal Engineering Research Center and Hydraulics Laboratory. Dr. James R. Houston is the Director of CHL and Messrs. Richard A. Sager and Charles C. Calhoun, Jr., are Assistant Directors. The report is a product of the Monitoring Completed Navigation Projects (MCNP) Program and represents a joint effort between CHL and the Pacific Ocean Division (POD) of the U.S. Army Corps of Engineers. The MCNP Program Manager was Ms. Carolyn Holmes, CHL. Program Monitors of the MCNP Program at Headquarters, U.S. Army Corps of Engineers were Messrs. John Lockhart, Barry Holliday, and Charles Chesnutt.

The Principal Investigator of the Agat Harbor Work Unit was Mr. David D. McGehee; and the seiche and current measurement program was conducted by Dr. David King, both of CHL. During the course of this study they were supervised by Mr. William Preslan, Chief, Prototype Measurement and Analysis Branch (PMAB), and Mr. Thomas Richardson, Chief, Engineering Development Division, CHL.

The POD Co-Principal Investigator was Mr. Stanley Boc. Coordination and local management at POD were the responsibilities of Mr. Frank Dayton, Environmental Engineer in the Guam Operations Office. Messrs. Boc and Dayton were supervised by Mr. George Young, Chief of the Civil Works Technical Section, Planning and Operations Division.

Local technical support on Guam was provided by Mr. Paul Tobiason, of Datacomm, Inc., Mr. Dean Henley of Integrated Systems Analysis, Inc., and Pacific Basin Environmental Consultants, Inc. Special thanks are owed to the U.S. Coast Guard Station on Guam and the crew of the USCG Cutter *Basswood*. Permission to use facilities at Agat and other logistics assistance were provided by the Port Authority of Guam. Their contribution to the study is gratefully acknowledged.

The following CHL personnel contributed to this study: the remote monitoring system and its software were designed by Messrs. Jay Rosati and Gary Howell. Installation of the system was planned by and conducted under the supervision of Mr. William Kucharski. Data analysis

and plotting were accomplished by Mr. James McKinney and Ms. Margaret Sabol.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Robin R. Cababa, EN.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
feet	0.3048	meters
inches	2.54	centimeters
knots (international)	0.15144444	meters per second
miles (U.S. nautical)	1.852	kilometers
pounds (mass)	0.4535924	kilograms
pounds per square inch	6.89	kilopascal

1 Introduction

The Monitoring Completed Coastal Projects (MCCP) Program was established by Headquarters, U.S. Army Corps of Engineers (HQUSACE) in 1981 to evaluate the performance of the Corps in planning, design, construction, and operation and maintenance of selected Civil Works coastal projects. The program was renamed Monitoring Completed Navigation Projects (MCNP) in October 1996. The MCNP is funded by the Operations and Maintenance (O&M) Division HQUSACE, and is managed by the U.S. Army Engineer Waterways Experiment Station (WES) Coastal Engineering Research Center (CERC). Oversight is provided by a Field Review Group composed of representatives of Corps Divisions with coastal interests, Technical Monitors from HQUSACE, and the Coastal Engineering Research Board. The program's objective is to acquire information through intensive monitoring of coastal projects for improving:

a. Project purpose and attainment.

b. Design procedures.

c. Construction methods.

d. Operation and maintenance techniques.

Potential projects are nominated by coastal Districts and selected for monitoring during an annual Program Review attended by the Field Review Group. Selection is based on the potential for improving general procedures for application at other sites or for solving site-specific problems. Agat Harbor was nominated for inclusion in the MCCP by the U.S. Army Engineer Division, Pacific Ocean (POD) and accepted for inclusion in the program in 1986. Monitoring and documentation were joint efforts between CERC and POD.

2 Project Description

Site Description

Agat Harbor is located on the western side of the island of Guam (Figure 1). Mean tide range is 0.4 m (1.4 ft).[1] Agat is fringed by coral reefs characterized by a broad, shallow flat with a near-uniform depth of 0.3 m mean lower low water (mllw) (i.e., nearly exposed at low tide) that extends about 1 km offshore. The face of the reef is live coral with a near vertical slope down to approximately -6 m. The face is extremely porous and rough due to the health and size of the coral formations, and is an excellent dissipator of wave energy. Further offshore, water depth increases rapidly at an average bottom slope of 0.2.

Agat is in the lee of the island with respect to the predominant easterly trade winds, so incident waves are usually low. Waves that do approach from the west break at the reef face, so the reef flat and harbor are quiescent the majority of the time. The island is routinely exposed to typhoons. Typhoon conditions can only be estimated, but conditions on the reef flat and the backshore will be violent.

The harbor was designed and built by the POD and the Port Authority of Guam (U.S. Army Engineer District (USAED), Honolulu 1981). Construction was completed in 1990. The harbor basin was excavated from the reef flat that runs for miles along the western shore (Figure 2). It is protected by a detached 300-m long rubble-mound breakwater. A 36-m wide by 4.2-m deep and approximately 300-m long entrance channel was excavated from the harbor across the reef flat. The channel enters the -6 m depths outside the reef face at a "notch" in the reef plan that is likely a natural channel through the reef face. Figure 3 shows the channel under construction, before excavation of the basin; Figure 4 shows the completed project prior to construction of berthing and shoreside facilities.

---

1 The original design and survey data were provided in English units. Data collected for this study are reported in metric units, with the exception of some overwater distances, which are provided in nautical miles, following nautical convention. See page viii for conversions.

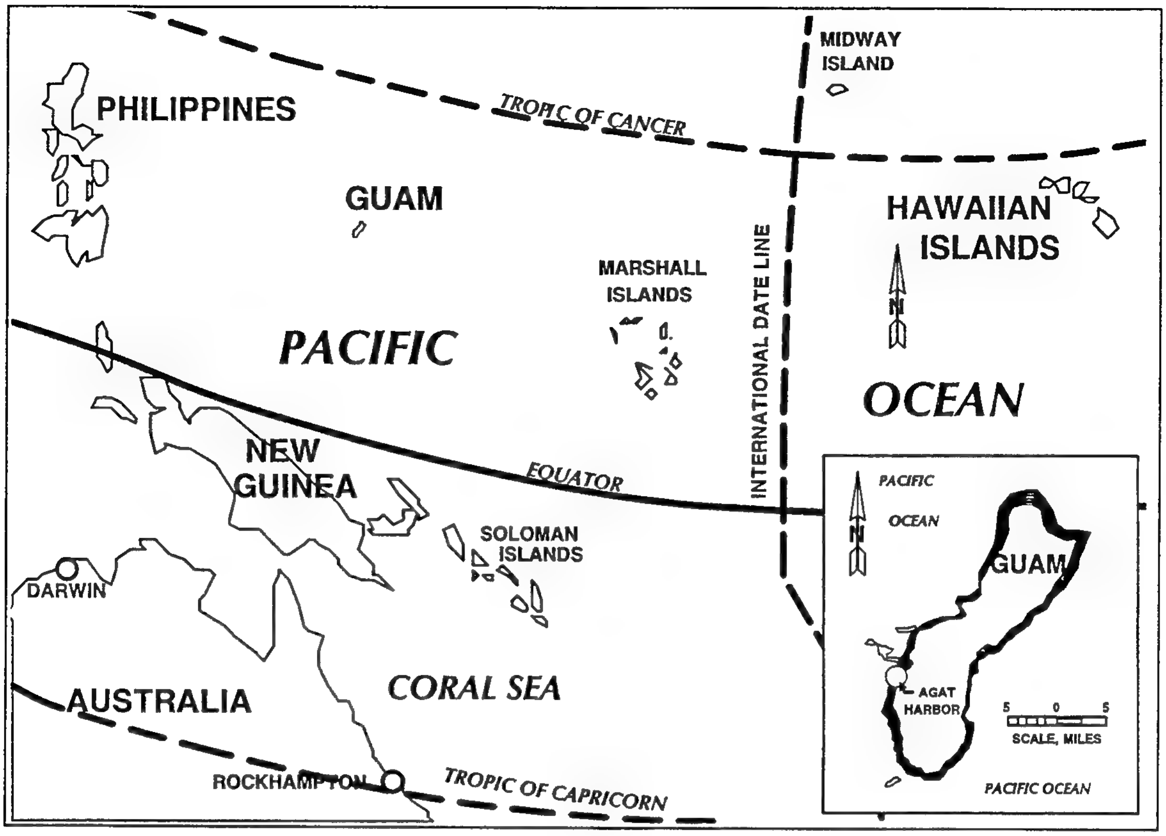


Figure 1. Location and site map of Agat Harbor, Guam

Design Criteria

The objectives of the project, as stated in the project report (USAED, Honolulu 1981), were to improve commercial and recreational boating facilities for Agat and improve socioeconomic opportunities for the people of Guam, while minimizing alteration of the reef environment. The technical criteria developed in that report for the harbor were:

a. The entrance channel should provide for two-way traffic and be navigable during all weather and sea conditions except during periods of severe storms, and the berthing area should be protected from severe storm waves during all conditions.

b. The plan of improvement should include a turning basin adequate for maneuvering of the design vessel and provisions for berthing and shoreside facilities.

c. Protective structures should be designed to withstand a severe combination of meteorological and oceanographic conditions that are characteristic of the study area (i.e., typhoon conditions).

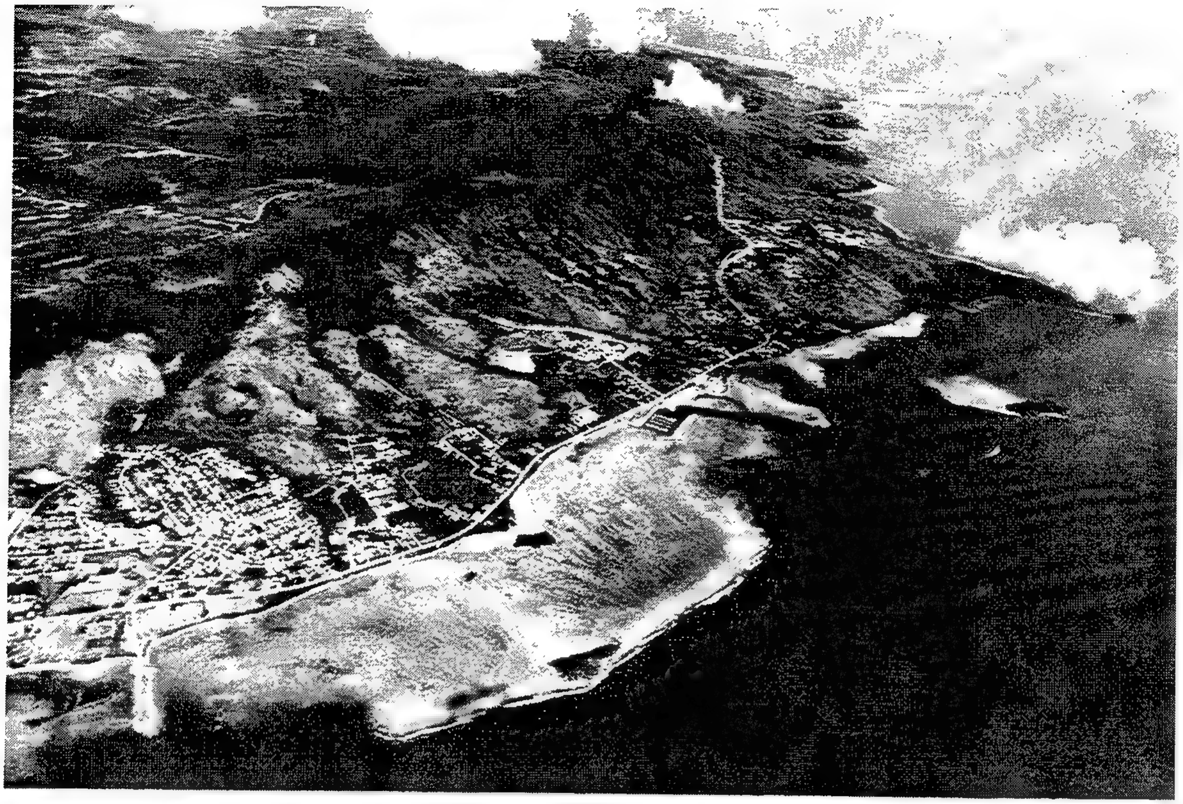


Figure 2. Aerial view of southwestern coast of Guam

d. The improvement design should limit design wave heights in the berthing area to less than 0.6 m.

e. The plan of improvement should be designed to accommodate a 60-ft-long design vessel with a 5-m beam and a 1.8-m draft.

Design Methods

Harbor plan

A preliminary harbor plan was developed by POD based on analysis of cost, economic benefit, and environmental impact. A more conservative plan with extensions to both ends of the detached breakwater and to the south revetted mole was suggested by CERC. The response of the harbor basins for these initial two, plus three other alternative plans, was modeled at CERC using the HARBS numerical model. The HARBS model is a finite element model that represents the harbor geometry inside a semicircular domain bounded by the shoreline on the landward side and a semicircular region of constant water depth on the seaward side. It assumes steady-state input conditions from a linear (small-amplitude), monochromatic wave; mild bottom slopes; and no current (Chen and Houston 1986).

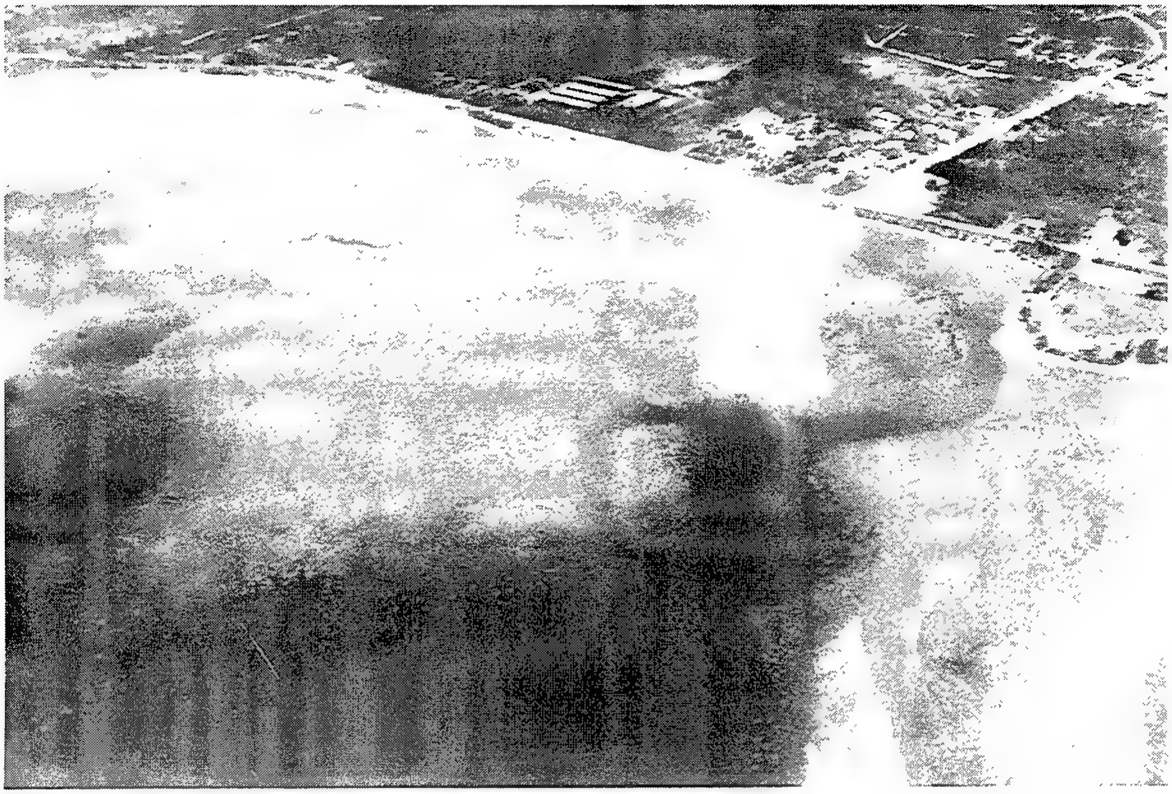


Figure 3. Agat Harbor channel under construction

Amplification factors were calculated for incident energy in 1-sec interval period bands from 8 to 20 sec and approaching from three incident angles. Output was reported at 32 locations (grid elements) within the harbor for the two initial plans and three alternative plans. The outer boundary of the numerical grid was within the reef flat. Three water levels were tested: 0.72 m, 1.4 m, and the 2.2 m design condition. The final plan recommended, Plan 4, extended the north end of the detached breakwater by 45 m from the original design (Farrar and Chen 1987).

Breakwater

Breakwater design was accomplished using standard practices found in the 1977 *Shore Protection Manual*. The Hudson formula was used to select the armor size for the design wave height. The design wave for the structure was selected as the depth-limited breaking wave at the structure toe, or 0.78 h, where h = water depth. The design depth assumed for the constructed plan was 2.5 m, derived from a mean higher high water level of 0.7 m, plus an estimated combined surge and wave setup of 1.4 m, over a reef flat with an average elevation of 0.3 m. The resulting design wave is 1.9 m.

Figure 4. Agat Harbor under construction

3 Monitoring Plan

Objectives

Agat Harbor was selected for monitoring because it has potential for providing information on an environment for which little engineering data exist.

Design guidance on wave characteristics on coral reefs needs improvement, as most data on wave shoaling and breaking are derived from observations of waves approaching sandy shorelines. Figure 5 contrasts the offshore profile at Agat with the typical equilibrium beach profile. Wave transformation across

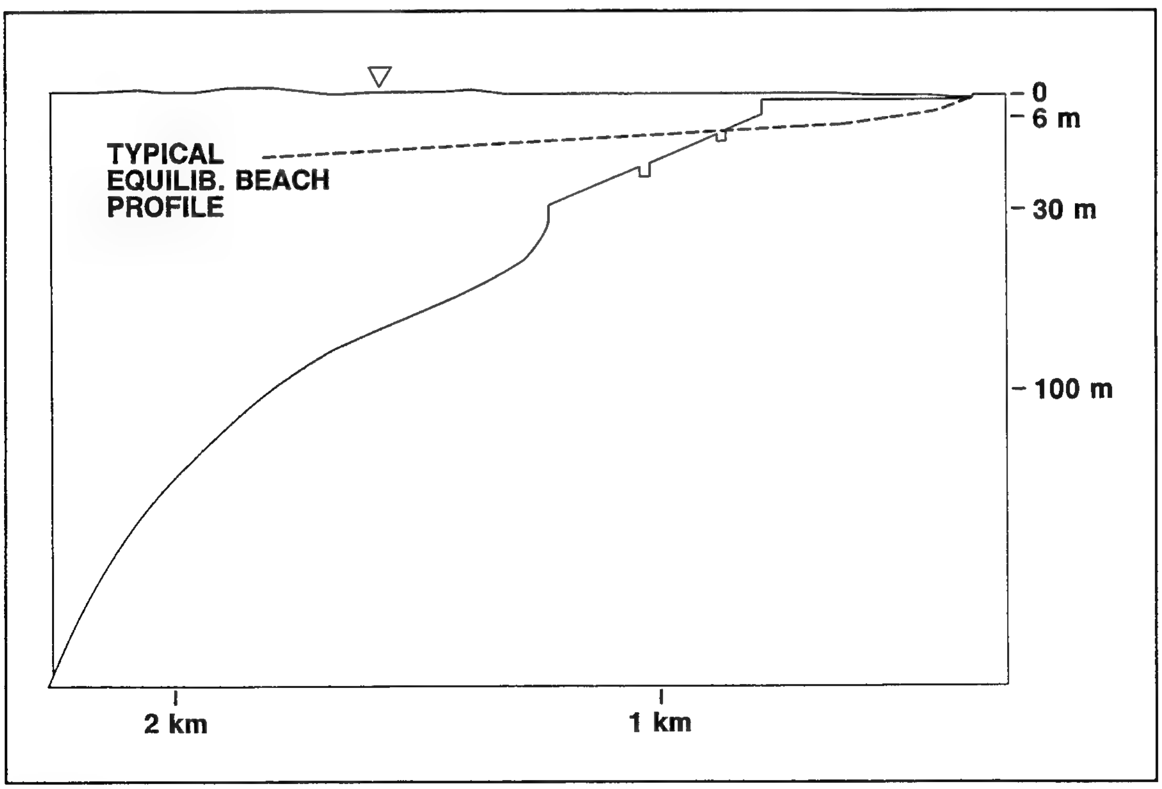


Figure 5. Idealized reef and sand beach profiles

this regime can be expected to be markedly different than across sand beaches. Even less information is available on maximum surge levels behind reef shorelines. How these factors affected the selection of the design parameters was an important but difficult question. The answer required observations during conditions at or near the design wave and surge conditions or at least conditions sufficiently energetic to cause structural damage. Unless a typhoon approached from the west during monitoring, there would be no opportunity to assess breakwater stability. Shoaling of the channel at the entrance was not expected because it was cut through limestone, and exited the live reef face where the water depth was well below project depth. Neither were impacts on adjacent shorelines anticipated, since there was little erodible material on the reef flat and upland areas. Nevertheless, the monitoring plan included periodic inspections of the structure and surrounding shoreline. The major issues to be addressed in the study were as follows:

a. Deepwater incident wave climate for the region around Guam.

b. Wave transformation across coral reefs as a function of depth and distance from the reef face.

c. Wave and surge levels behind coral reefs during large wave events (distant storms to the west would produce large incident waves, even without a local typhoon).

d. Validation of the HARBS model.

e. Wave transformation down steep-sided channels.

f. Response of project and adjacent shoreline.[1]

Monitoring Elements

A monitoring plan was developed to examine these issues through analysis of data collected over a 3-year observation period (Boc and McGehee 1989). Elements of the monitoring effort are related to the study issues. As is usually the case with coastal engineering field studies, the "ideal" monitoring plan had to be modified to accommodate instrumentation, logistic, and economic constraints. The elements of the plan, referenced by letter to the issues are as follows:

a. Directional wave energy spectra and surface winds from an offshore site.

1 Issue g, "Wave-induced circulation on a reef flat," is discussed on pages 18 and 19.

b. Wave energy spectra at several locations on a shore-normal transect across the reef flat.

c. Wave conditions and water elevations at the structure, and harbor response during large wave events.

d. (1) Directional wave energy spectra at the outer boundary of the model.

(2) Wave energy spectra at several sites within the harbor.

e. Wave energy spectra at the outer and inner ends of the channel.

f. Periodic site inspections and aerial photographs of the harbor and surroundings.

Element *a* requires a long, continuous record to obtain the distribution of calm conditions as well as the extreme events that describe the wave climate. Elements *b-e* require a range of conditions above some threshold of interest, ideally including the modeled incident conditions. In order to capture a sufficient range of conditions, including episodic events, it was considered desirable to monitor these sites continuously over the course of the study. Periodic measurements or experiments were not considered initially because of the difficulty of synchronizing measurements with events of interest and because these events develop rapidly, making it difficult to fix instruments securely in place before conditions become too violent for placement.

The preferred position for measuring the incident climate is directly offshore of Agat in deep water. These depths are attained relatively close to shore, but instrument constraints, discussed below under "System Design; Data management," forced a position further offshore. Initially, a site southwest of the island (1A) was selected; a second site to the northwest (1B) was designated to improve performance (see Appendix B, "Performance Critique").

Gauge placement in the channel and harbor posed no particular logistic restrictions, allowing sites to correspond to the channel beginning and end (sites 5A and 5B), and with three of the HARBS model grid points (sites 4B 4D). Site 5A also represents incident wave conditions approaching the reef face. Three sites were selected on the reef flat: 2A, directly behind the reef face; 2B, at 25 percent of the distance from the face to the shore; and a third, 4A, at 50 percent. By selecting the third site on the reef flat at the transverse position of the breakwater, but displaced to the side to avoid reflected energy, it serves elements b and c. By using a directional gauge, and selecting a position at the outer boundary of the HARBS model, it also serves element d1. Figure 6 shows the planned layout of the gauges.

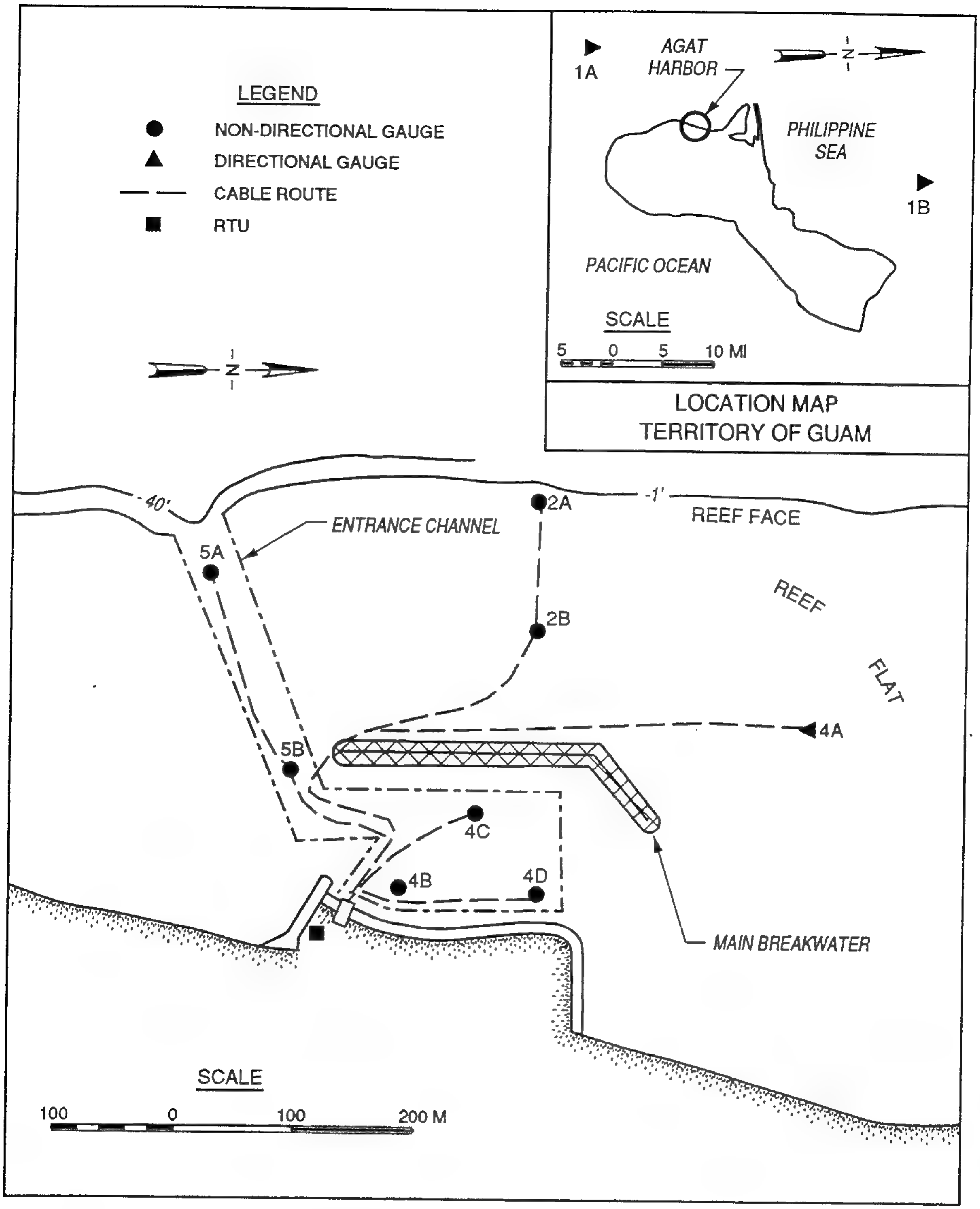


Figure 6. Plan of nearshore gauge locations

System Design

General requirements

Agat Harbor is a recreation and fishing marina with frequent boat traffic. In addition, tourists and fishermen regularly wade over the reef flat area. Any instrument left in situ must not pose a risk or obstruction to the public, yet it must be protected from accidental or deliberate encounters. Electrical power at the site is occasionally lost during normal weather events, and will likely fail for days after a typhoon. Travel time from Vicksburg, MS, added to the advance permission required for government employees to travel overseas, makes technical support from CERC a long lead-time option. The system should be as automated as possible, and yet serviceable by local technical support. Equipment must be protected from, or designed to withstand, high temperature and humidity conditions.

Wave and wind measurements in deep water are most efficiently obtained from a surface-following buoy. The National Data Buoy Center (NDBC) has developed a standard, 3-m-diam buoy that provides directional wave information every hour, as well as wind speed and direction, air pressure, and air and sea surface temperatures (Steele et al. 1990). It is a rugged, self-contained observation platform designed to operate up to 2 years under battery and solar power.

Individual, self-contained instruments were rejected for the nearshore sites for two reasons: (a) the expense of routine change-out required of the commercially available instruments over the course of the multi-year study (particularly on the deeper sites, where diving was required); and (b) the risk of loss of the instrument, and more importantly, the data, in the shallow, clear waters. An integrated system with sensors cabled to a central data processor/logger was specified for the nearshore sites to minimize the number and size of underwater components; to permit long-term, unattended operation; to ensure capture of all data prior to any sensor loss/damage; and to reduce system cost. An air-conditioned administration building at the harbor was made available by the Port Authority of Guam to house the central data management computer and power supply.

Sensors

The NDBC buoy is a discus-hull, surface-following pitch-roll-heave buoy. It measures waves with its onboard accelerometer and tilt sensors. See Steele et al. (1990) for additional information.

The basic sensor selected for the nearshore system was the pressure transducer. Mounted on the seafloor, it can accurately measure waves and water levels, is rugged enough to survive the environment without obstructing traffic, and will operate without frequent maintenance. Sensor elevation can be readily measured on the reef flat and, with more difficulty, in the channel.

Three sensors arranged in a slope array produce the cross spectra used to measure directional waves. The transducers are sealed in 10-cm diam by 25-cm long cylindrical pressure cases. Pressure is transmitted via a flexible diaphragm on one end and through an oil-filled passageway to the transducer. A copper-nickel alloy cover plate prevents biofouling of the diaphragm.

An atmospheric pressure correction must be applied to an underwater pressure measurement to produce an accurate water level. An eleventh, above-water transducer was added to the system as a barometer to provide this information.

Cables

Seven-conductor, double-armored, 1.3-cm diam cable is used to carry power to and signals from the pressure transducers. Waterproof connectors are spliced onto the cable at the transducer end to permit changing sensors, if required. The cable is allowed to self-bury in the channel and the harbor, but on the reef flat is pinned every 200 m with 1-m long "J" clamps driven into the coral. This prevents tampering with the cable and protects against abrasion from the coral due to wave action. Sensors 5A and 5B are connected to a single cable; the remaining six sites have individual cables. The seven cables converge under the fuel dock at the southeast corner of the harbor and feed into the administration building through a conduit placed by the Port Authority during construction of the marina complex.

Mounts

The single-point transducers are mounted horizontally on 400 kg railroad wheels. A steel, hinged cylinder, containing the transducer and the cable splice, is sealed by stainless steel bolts with one-way nuts (Figure 7). The steel cylinder can only be opened by shearing the bolts.

The slope array has three transducers mounted vertically in cylinders on radial arms welded to a central wheel (Figure 8). A larger hinged cylinder contains the electronic module described below. A single cable carries the multiplexed signal from all three transducers.

Signal processing

The nearshore instrument control system features programmable data transfer and intermediate solid state buffer from remote transmitting units (RTU's) capable of handling six data channels. Three RTU's, located at the shore end of the underwater cables in watertight stainless steel enclosures, are used: GU1 controls sensors 5A, 5B, and the barometer; GU2 controls sensors 2A, 2B, 4B, 4C, and 4D; GU3 controls the slope array, 4A. The slope array

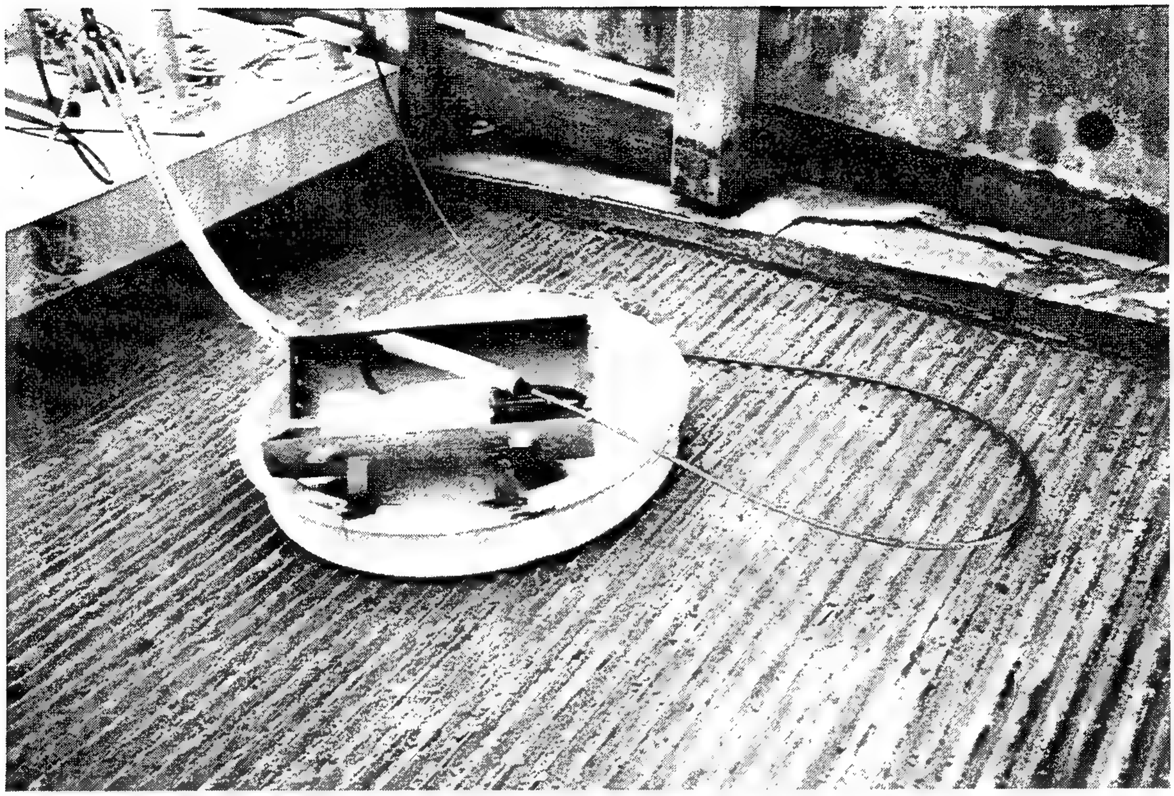


Figure 7. Single point transducers housing and mount

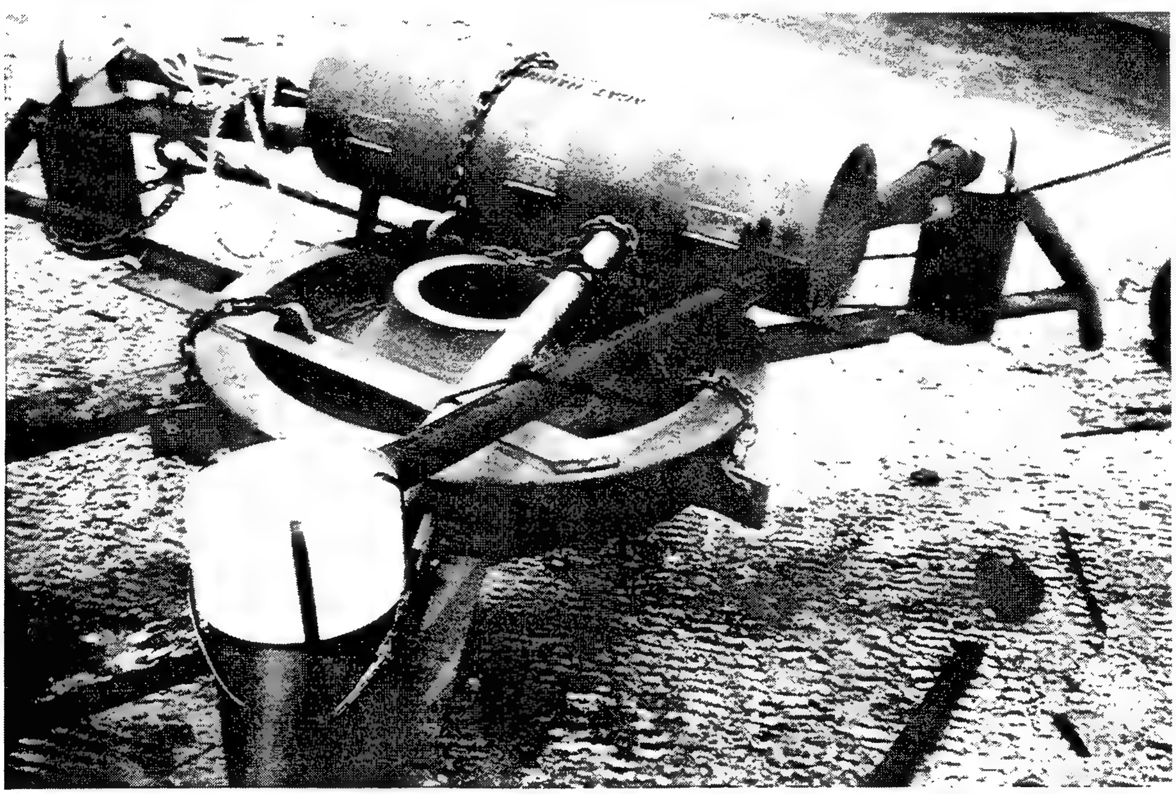


Figure 8. Slope array transducers/electronics housing and mount

contains an additional underwater module, the serial asynchronous unit (SAU), that performs A-D conversion and multiplexing of the three transducer signals. It contains a compact, single-board central processing unit (CPU) that samples the sensors and outputs a serial data stream to the RTU. The RTU powers the transducers (or SAU), controls the sampling rate and burst interval, and transfers buffered data files to the next output device.

Data management

All time series measured by the buoy are analyzed and reduced on board, then burst-transmitted every hour via VHF radio to the GOES satellite network. This "line-of-sight" telemetry link had a direct impact on the buoy's deployment site. While the preferred position for the incident climate measurement would have been directly west of Agat, the low azimuth of the western GOES satellite at this longitude placed it below the elevation of Guam's central mountain range. Consequently, the buoy had to be placed either north or south of the island. An initial location, Site 1A, was selected about 10 n.m. west-southwest of the southern tip of the island (see Figure 6).

Onshore, data capture was designed to occur at three locations. The RTU contains battery-backed memory cards with a capacity of about 256 KB, enough for about 48 hr of data. This was considered adequate as an intermediate buffer to hold data during temporary downtime of the main data logger. The main data processor and logging device was a Digital Equipment Corporation microVax II computer running under UNIX. Records are written into its database on a 380-MB hard disc drive, and backed up onto a TK-70 cartridge tape, with a capacity of over 200 MB. Tape cartridges were scheduled to be recovered locally once a month and returned via mail to CERC for analysis and storage. Remote data retrieval via telephone was possible, but not considered as the primary method because of the cost of the telephone connection. The data management scheme is illustrated in Figure 9.

Software

There are two nested routines controlling onshore data collection and storage. Each RTU has a programmed sampling scheme, and writes an integer count associated with the measured output voltage from each sensor, along with the time word, into a directory. The microVax, in turn, queries each RTU's directory for records not previously retrieved every 20 min. It downloads these records using KERMIT, an error-free file transfer protocol, at 4,800 baud, and updates its relational database (Interbase). Attributes in the database include sensor data, such as serial number, calibration factors, and position, that permit automatic analysis of the raw time series. Once a day, the database is automatically copied onto the cartridge tape. The only manual operation required is (monthly) tape replacement.

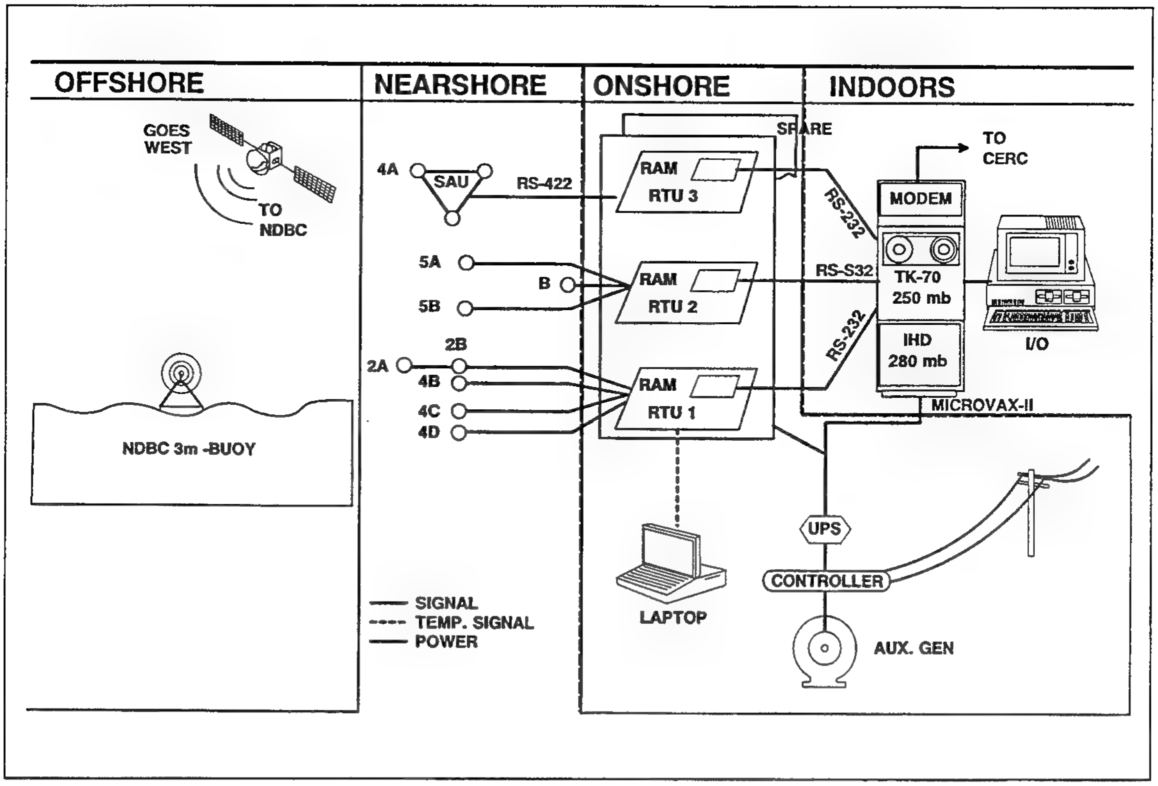


Figure 9. Data management scheme

The distributed features of the database facilitate remote access using anasynchronous DECnet link with Vax mainframe computers in Vicksburg, or any UNIX-based system running Interbase. The mainframe's database can be updated from the remote's database using Interbase record transfer commands. Similarly, changes in the database relations, or new versions of software modules, can be readily transferred to the remote computer from the mainframe.

Power supply

The primary power for the NDBC buoy is a nonrechargeable dry cell battery. The secondary power system consists of rechargeable lead-acid batteries and solar panels. The system draws continuously from both sources, but will not continue to operate after the primary battery is discharged. Typical life cycles are on the order of 18 months to 2 years.

Onshore, a major design consideration was to provide continuous power to the microVax and the RTU's for both the routine and major losses of line power. A 2-kW uninterruptable power supply is wired inline with the circuit for the system. It provides continuous, regulated voltage and will power the system for short dropouts of line voltage. If power loss lasts more than 30 sec, a 15-kW diesel generator mounted on an elevated platform adjacent to the administration building automatically starts. It has sufficient fuel to power

the system for several days. Another redundant feature is a complete backup set of RTU's installed adjacent to the primary set. Switching RTU's is accomplished in a matter of minutes by switching the waterproof cable connectors.

Analysis and Sampling Plan

Spectral analysis of discrete samples of surface elevation is an accepted method for obtaining useful wave parameters from a random sea. It is based on linear superposition, and thus restricted to first-order wave theory. Transformation into the frequency domain produces a power spectrum that provides energy distribution in discrete frequency bins. The method generally follows CERC's Wave Data Analysis Standard (Earle, McGehee, and Tubman 1996), though the higher sampling rate produces a spectrum that differs from the CERC standard. Table 1 gives the sampling and analysis parameters for the shallow-water sites.

Table 1
Sampling and Analysis Scheme for Onshore System

Site No.	Sample Rate (Hz)	Sample Length (count;sec)	Sample Interval (hr)	Segment Length (count;sec)	Spectral Bandwidth (Hz)	Number of Bands
2A,B; 4B-D	2.5	2560;1024	2	512;204.8	0.0049	57
4A	2.5	4500;1800	2	512;204.8	0.0049	57
5A,B,C	1	3540;3540	1	256;256	0.0039	64

An energy-based significant wave height *Hmo,* is estimated using the formula

$$Hmo = 4\left[\int_o^{\infty} S(f)\,df\right]^{1/2} \tag{1}$$

where *S(f)*, the nondirectional energy spectrum, is band-pass filtered. The peak frequency *fp* is defined as the frequency at which *S(f)* has a maximum. If the slope of the sea surface is included, directional information can be obtained from the cross power spectrum. The cross power spectrum *Pmn* between pairs of sea-surface fluctuations at *m* and *n* is related to the surface spectrum by

$$Pmn = \int e^{iKXmn}\, S(f,\theta)\, d\theta \tag{2}$$

where *K* is the wave number vector, *f* is frequency, θ is direction, and *Xmn* is the difference between two position vectors *Xm* and *Xn*. The dominant wave direction, the mean direction from which the energy is coming at the peak

frequency, can be calculated from $S(f,\theta)$, the two-dimensional sea surface spectrum (Longuet-Higgins, Cartwright, and Smith 1963).

The standard sampling scheme used by NDBC to observe wind waves is a 20-min burst of samples taken at 2.56 Hz every hour. Data are spectrally analyzed onboard the buoy which produces a directional spectrum of the wave energy with periods between 2.5 sec and 33 sec.

A site visit was conducted in June 1988 while the project was under construction. Visual observations of waves on the reef flat during calm conditions revealed a highly nonlinear cnoidal profile, characterized by discrete, widely spaced (on the order of 100 m), steep-faced crests (on the order of 10 cm high). There were no discernible troughs, but between crests the water flowed shoreward. In short, the waves more closely resembled a periodic series of bores. To adequately capture the steep crest profile, the sample rate for the reef and harbor gauges was selected to be 2.5 Hz, rather than the 1-Hz rate typically used in shallow-water sampling. That decision, because of limited memory capacity (see "System Design"), forced a corresponding reduction in sample length, which in turn, restricted the lowest observable frequency to 0.0049 Hz, or a corresponding period of about 200 sec. While well below the wind-wave energy band, this constraint turned out to be significant later in the study.

The channel gages, 5A and 5B, were in deeper water where linear wave forms are expected, so they collected the more standard 1-Hz samples. Since they were also selected to establish the gradient between interior and exterior water levels, they operated nearly continuously (59 min/hr). Nine mean water levels per hour (6-min average) could be extracted from these time series.

System Installation

Installation of the harbor and channel sensors could have been accomplished using local fishing/work vessels, but installation of the reef flat gauges posed a logistics problem. No local vessel was found that had the lifting capacity to deploy the 400-kg sensor mounts, carry and lay the cable, and yet draw little enough water to operate on the reef flat without risking damage to itself or the reef. The solution was a customized, outboard-powered work barge, 3.6 m by 1.8 m by 0.3 m, with an A-frame and hand-cranked winch. The vessel was designed by CERC and fabricated of No. 6061, 7-mm aluminum plate by the Construction Services Division at WES (Figure 10). The entire instrument system and deployment equipment, including the barge, was shipped as containerized cargo to Apra Harbor, Guam. Installation was performed by CERC in August 1990. The NDBC buoy was deployed the following month using the U.S. Coast Guard buoy tender *Basswood*.

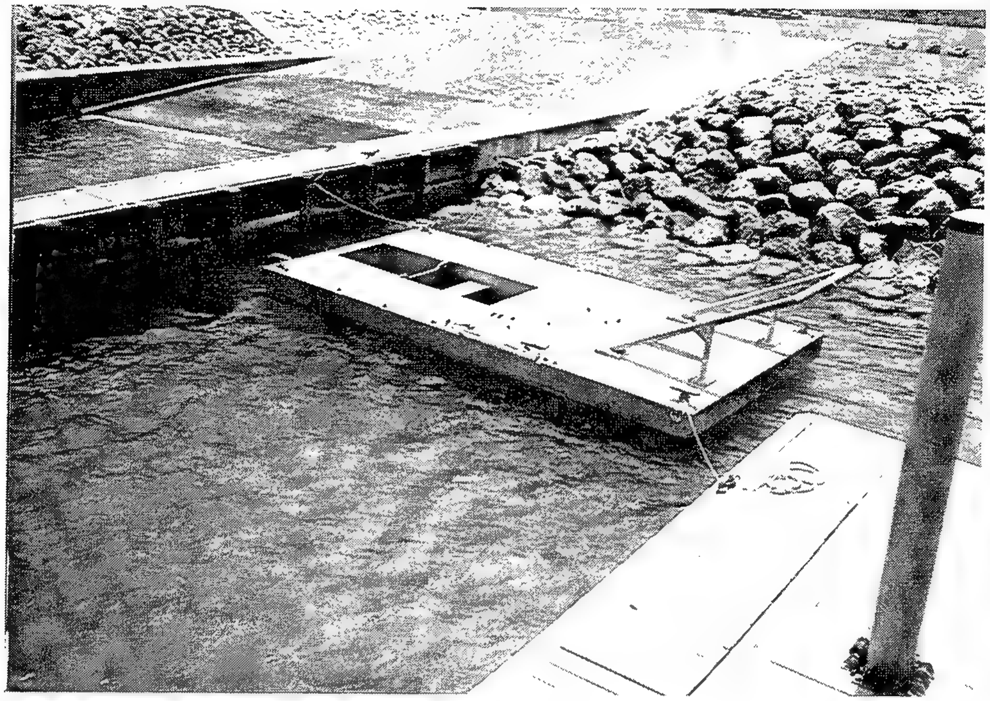


Figure 10. Custom gauge deployment barge

The Unanticipated Monitoring Element

It was assumed during the design of the project and development of the monitoring plan that water currents on the flat were governed by the low-amplitude tide signal. While circulation was considered from a water quality standpoint (hence the detached breakwater design), currents were assumed inconsequential in structural considerations. However, the author's observations from shore during a site visit in July 1991 (before instruments were operative) revealed unexpectedly large currents, and provided an indication of the processes that likely govern during extreme conditions. The crude, visual estimates of waves and currents provided below will help visualize the phenomenon.

On that occasion, a distant storm westward of the island was causing a 3- to 5-m swell to break on the reef face. Most of the incident energy was dissipated in breaking, so that incident waves reaching the breakwater were less than 1/2 m in height. Mean water depth on the reef flat was about 1 m. A significant current was evident flowing southward, parallel to shore. The current pulsated, varying in magnitude but without reversing direction, at irregular cycles of about 5 - 10 min. The current extended far enough offshore to flow around the outer breakwater, but the highest velocities occurred across the open northern side of the harbor, between the shore and the breakwater. The velocity of the water varied irregularly from less than 0.5 m/sec to over 3 m/sec, but generally was in phase with periodic oscillations of the water level in

the harbor; i.e., as the water level in the harbor fell, the flow into the harbor increased in velocity. Water level fluctuations in the harbor approached 1 m. The water level on the reef flat also varied, but with about half the amplitude of the harbor fluctuations. The lowest stage attained in the harbor was below the level of the reef flat at the northern boundary of the boat basin; at those times, a weir with a drop near 0.3 m developed as the water poured into the harbor. This condition persisted with irregular variations in amplitude and period throughout the day. When offshore wave conditions subsided to 1 - 2 m the next day, no circulation was apparent on the reef flat.

Though system installation was already under way, it was obvious that another element was needed in the monitoring plan; that is, element *g*, current measurements in the harbor and on the reef flat.

While long deployments were practical for the wave sensors (see "System Design," above), the unavailability of a reliable, long-term in situ current sensor forced another approach for element g. Since current measurements during energetic - but not necessarily extreme - events were desired, short-term (order of days) measurements would suffice if deployment could occur on short notice and before conditions became unsafe. One approach was use of a local contractor to deploy lightweight instruments that could be carried over the reef on foot and hand-deployed. A contract was awarded to Pacific Basin Environmental Consultants, to install and operate CERC-provided instruments. Water levels and currents were measured from battery-powered, internal recording pressure sensors and impeller-type current meters. Drogues were also provided to track surface currents. The sampling interval was set at 10 sec, effectively filtering wind-wave energy but passing energy with periods on the order of 30 sec and longer. Figure 11 shows the locations selected for placement of the pressure sensors on the reef flat north of the harbor. Details of this effort can be found in Appendix A, which contains the original and modified work statement for the contract and the contractor's data reports.

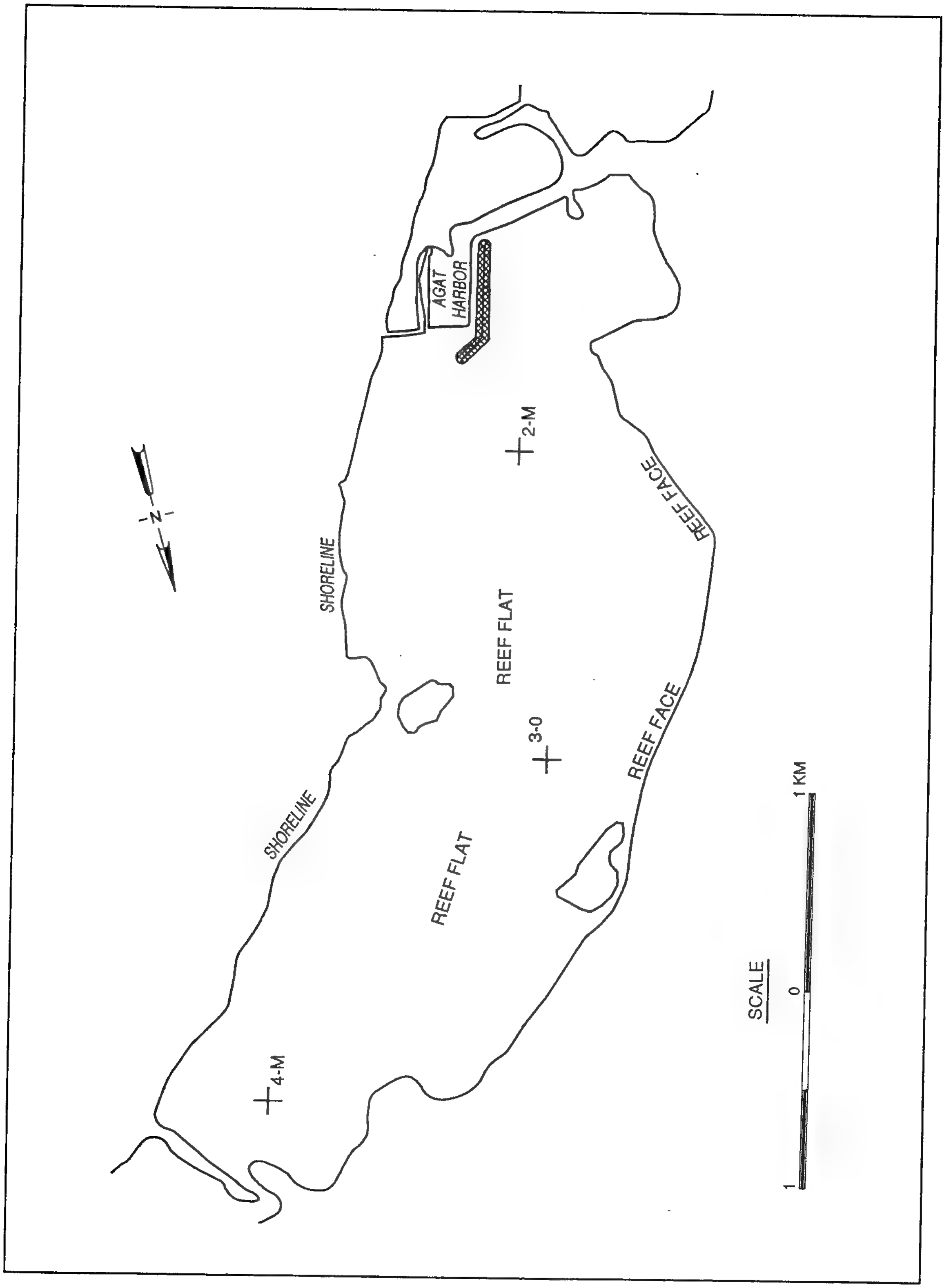


Figure 11. Short-term pressure sensor deployment sites

4 Monitoring Results

Performance

Design and construction of the nearshore system and buoy occurred in fiscal year (FY) 88 and FY89, while the harbor was still under construction; deployment occurred in the summer of 1990. Activation of the nearshore system was delayed until February of 1991 while awaiting completion of the administration building, in particular the electric service. Tantalizingly, Typhoon Russ struck while the transducers sat idle on the reef flat. On 18 December 1990, it skirted the southwest side of the island, establishing ideal conditions (from the perspective of the monitoring plan's goals). If the nearshore system had been on during that storm, objectives 2-5 of the monitoring plan would have been attained 4 months after its installation. The pattern appeared to be set for the rest of the study - whenever everything was operational, conditions were likely to be mild.

A second typhoon, Omar, crossed directly over the harbor from the east on 28 August, 1992 (Figure 12). None of the wave measurement systems were operational, but some data were captured using the short-term, self-contained water level gages. Self-contained gages were also deployed at the end of October 1992 for Typhoon Brian. This time the offshore buoy and the nearshore system were operational, but because the storm track was westward, large waves ($H \cong 4m$) were not felt on the western side of the island until after the typhoon's passage. The third typhoon of the 1992 season was Typhoon Gay in late November, a relatively small storm that passed well offshore to the east. Data were recovered from the offshore buoy and the reef gages, using the solid state memory in the RTU. No other typhoons approached the island for the remainder of the study. Data collection was terminated at the end of FY93.

Periods of operation for the various instruments are shown graphically in Figure 13 as a time line, together with the offshore significant wave height to illustrate the conditions under which simultaneous data were (or weren't) recovered. Overall data recovery for the buoy was no better than 60 percent, and less than 30 percent for the nearshore system. This compares with average performances of 80 to 90 percent for most other wave stations managed by CERC and NDBC. High data return was not, in itself, required for either

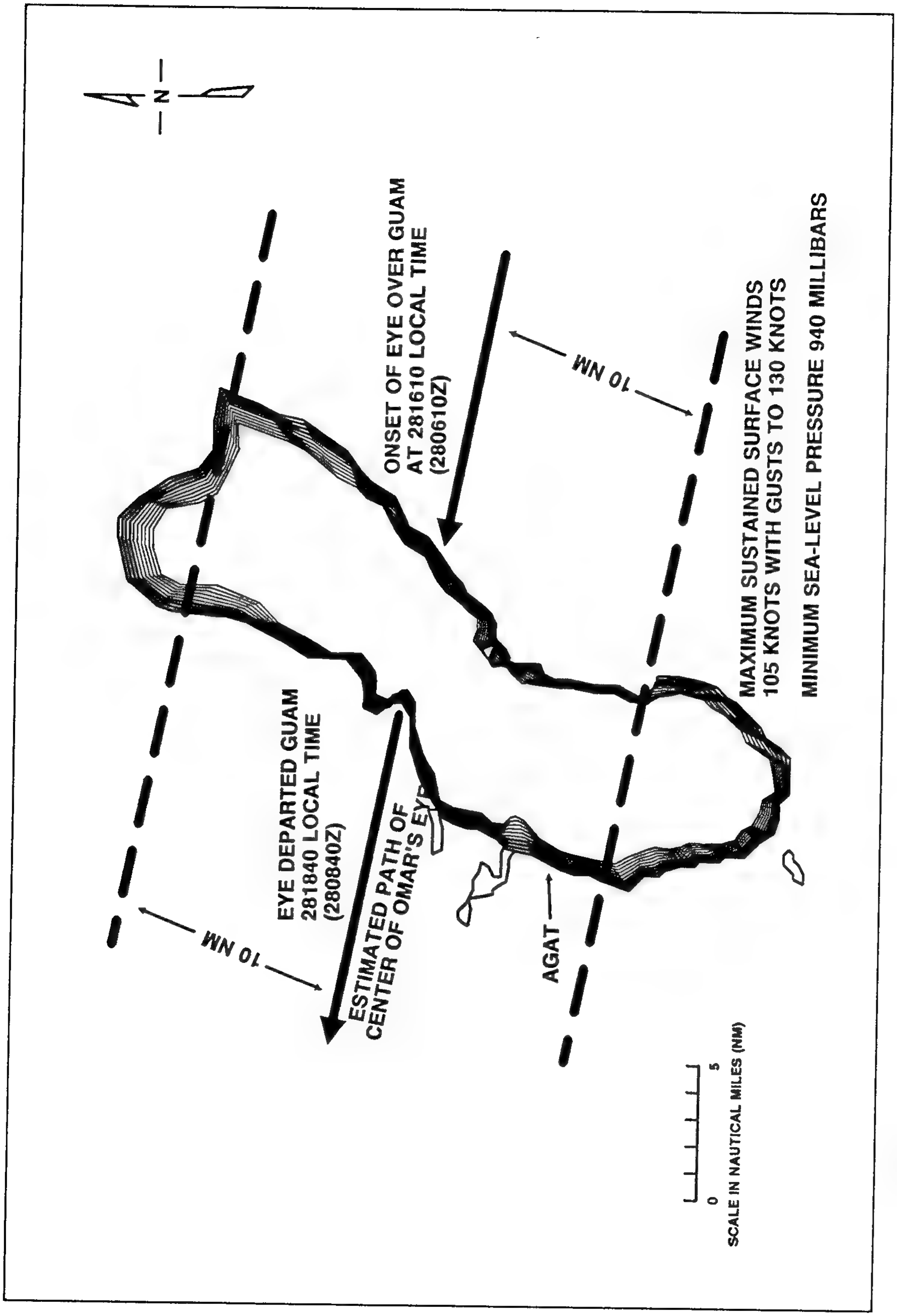


Figure 12. Typhoon Omar, Guam, 28 August 1992

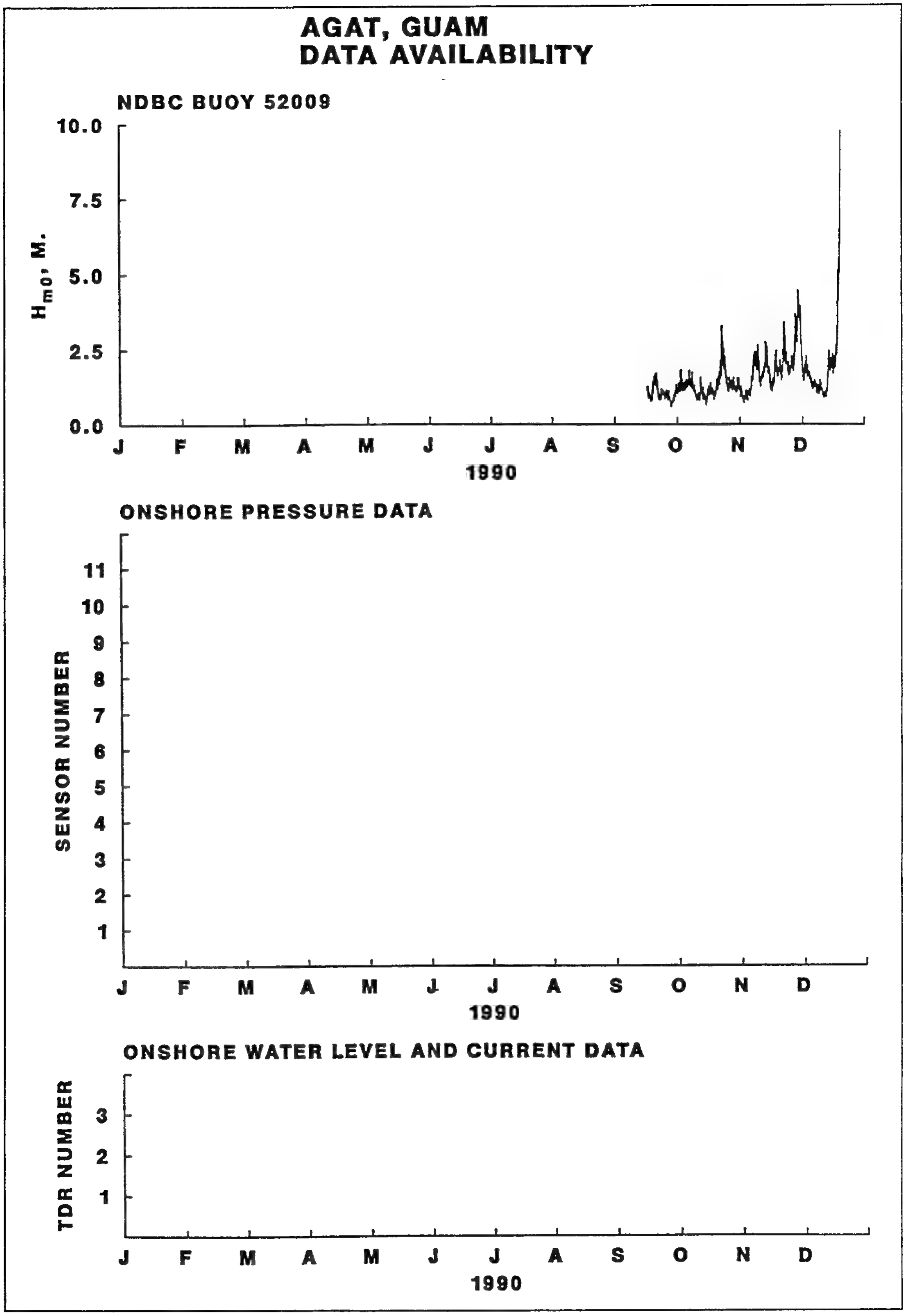


Figure 13. Data capture performance and offshore wave height, by year (Sheet 1 of 4)

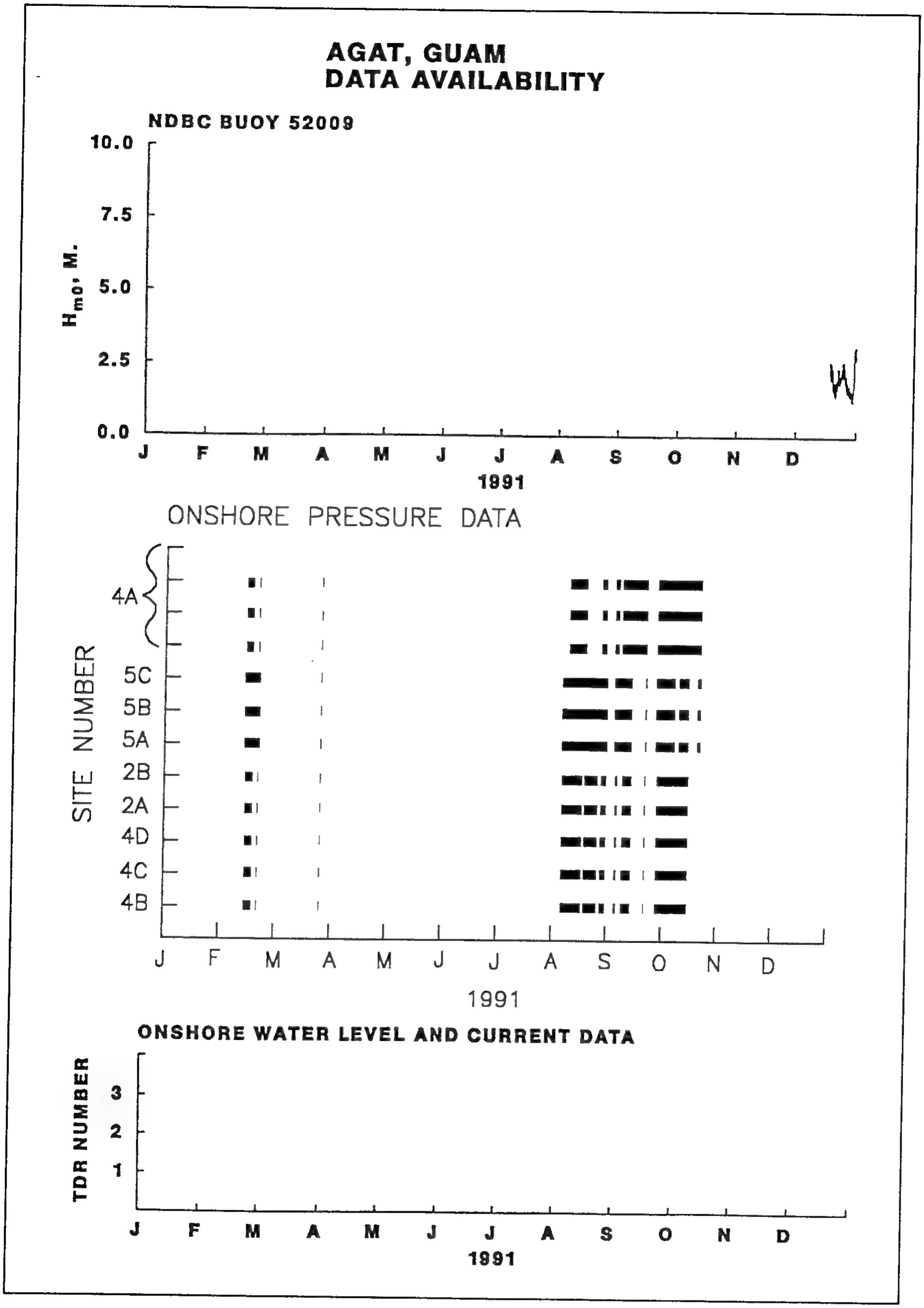


Figure 13. (Sheet 2 of 4)

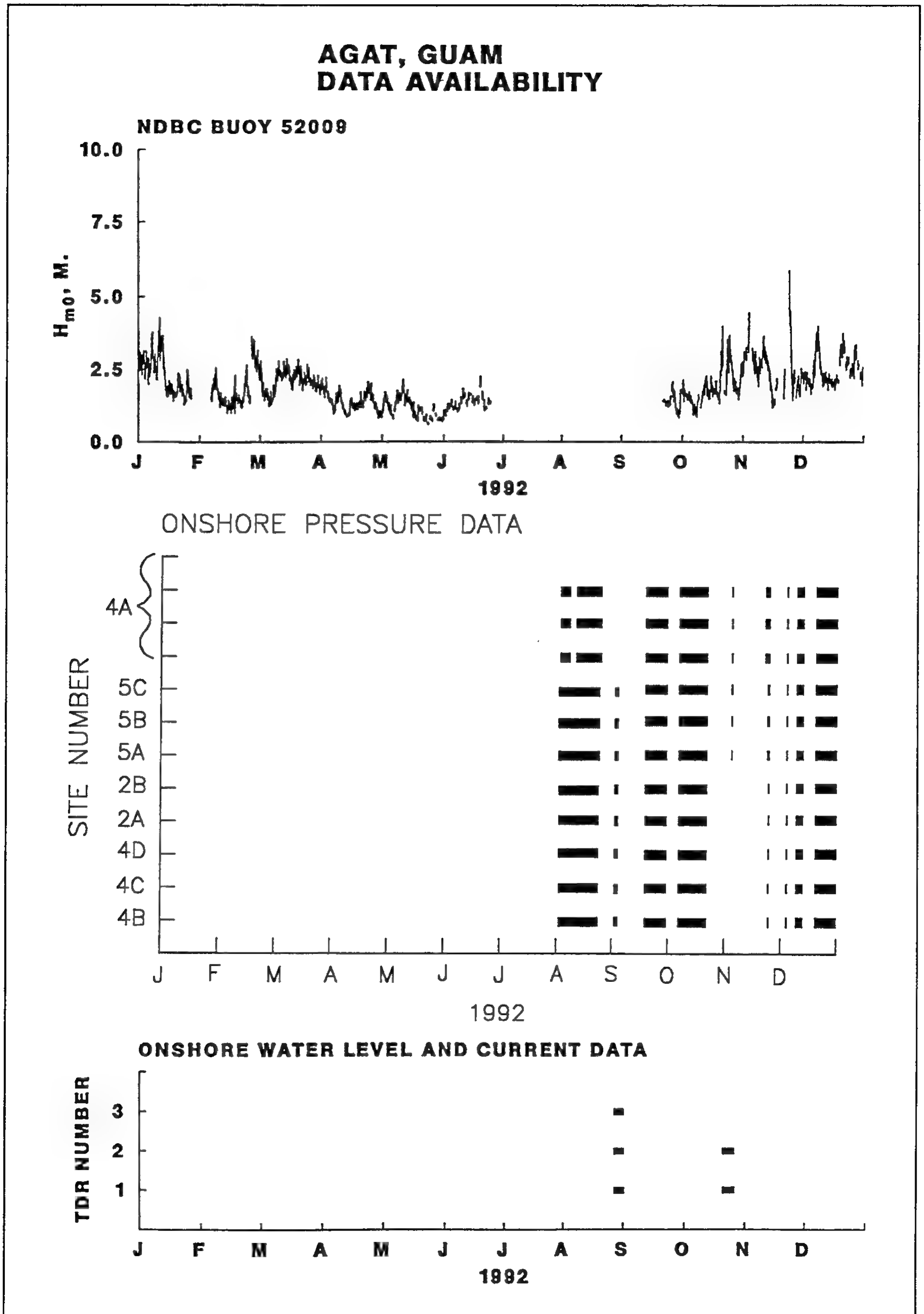


Figure 13. (Sheet 3 of 4)

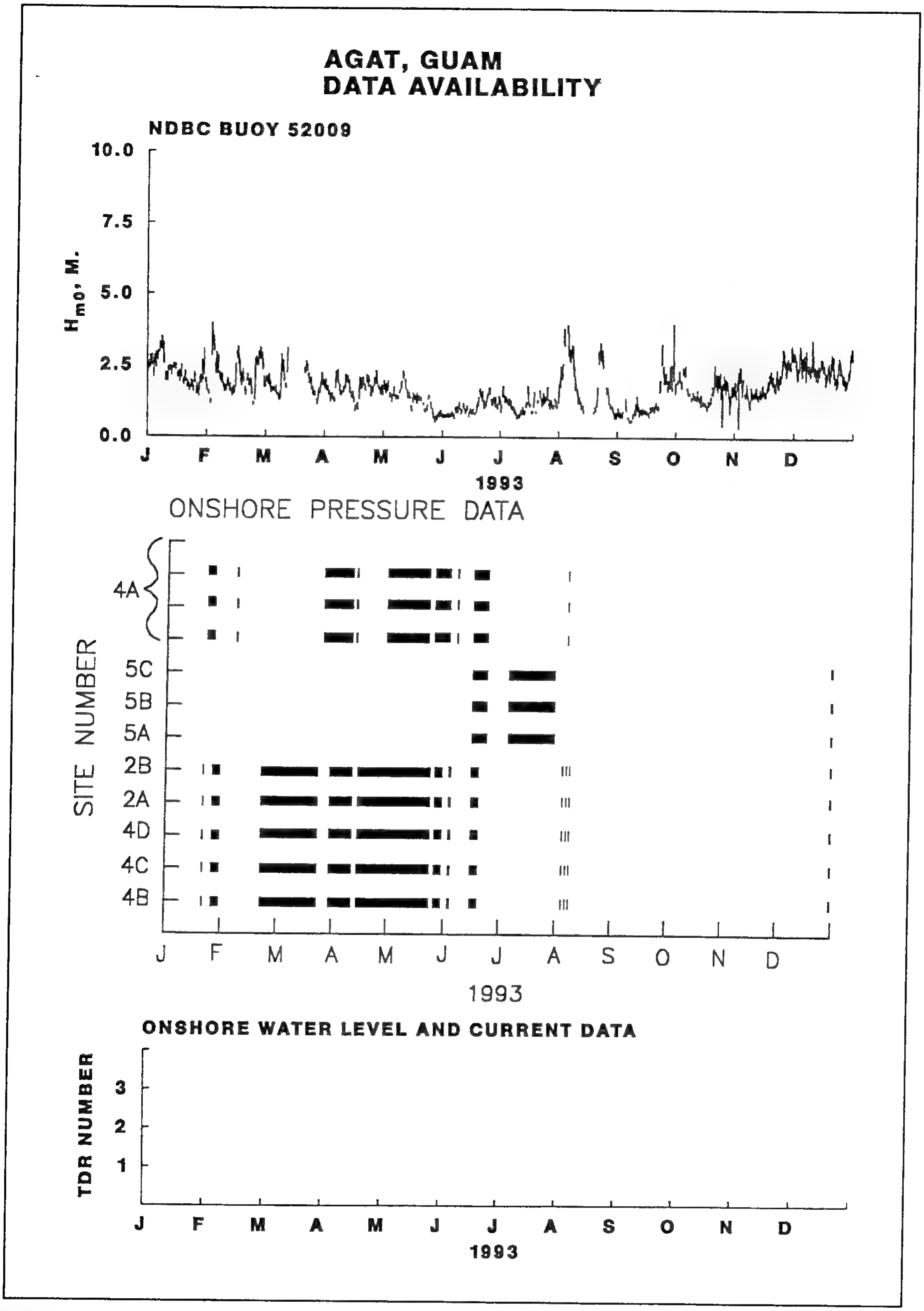


Figure 13. (Sheet 4 of 4)

system; rather, it was the means intended to capture extreme events. In fact, once they malfunctioned, each system was allowed to remain idle between typhoon seasons to conserve mobilization and shipping funds (e.g., surface freight versus air freight for the buoy). Nevertheless, the lower than anticipated data return rate of the study warrants examination to extract useful lessons for future efforts. Some of the causes, which ranged from chemical to orbital, and potential solutions are discussed in Appendix B.

Results

Results will be provided according to the lettered objectives presented in Chapter 3 (page 8).

a. *Incident wave climate.* Insufficient data were recovered from station 52009 to develop a usable climate based on extremal analysis, but the data that were collected represent the longest directional wave record available anywhere in the Equatorial Pacific. Appendix C combines summary statistics for both deployments (mean and largest conditions, by month; joint frequency of occurrence of height and period, by direction band). Figure 14 is a rose plot of the mean wave heights by direction.

   Unique measurements of deepwater directional spectra were obtained during the approach of a typhoon that will provide valuable "outer envelope" information for wave generation models. Figure 15 shows the path of Typhoon Russ relative to the island and the gauge. Also plotted are the history of the separation distance between the buoy and the storm center and the measured significant wave height. The approach and arrival of Typhoon Russ are obvious in the data. The buoy failed when the center of the storm was a distance approximately the radius of maximum winds away, so the last few wave heights measured, though still increasing, probably represent the peak conditions. Typhoon conditions were also captured during typhoons Brian and Gay. Appendix D contains plots of the complete time series of wave heights, periods, and directions for all available data.

b. *Wave transformation.* Most of the data recovered represent the normal condition on the leeward side - flat calm. Instances of simultaneous operation of the offshore gauge and the three gauges along the reef flat (2A, 2B, and 4A) when significant energy was approaching from the west, were rare. Table 2 summarizes the times and reduced parameters selected for further discussion. They are representative of energetic conditions for both low and high predicted tidal elevations. Direction of approach of the incident waves ranges from 217 to 299 deg true north. The measured depths listed are from site 2B, and are somewhat (say 1/2 m) deeper than typical water depths on the reef flat because the gauge was placed in a local depression. The energy levels (as

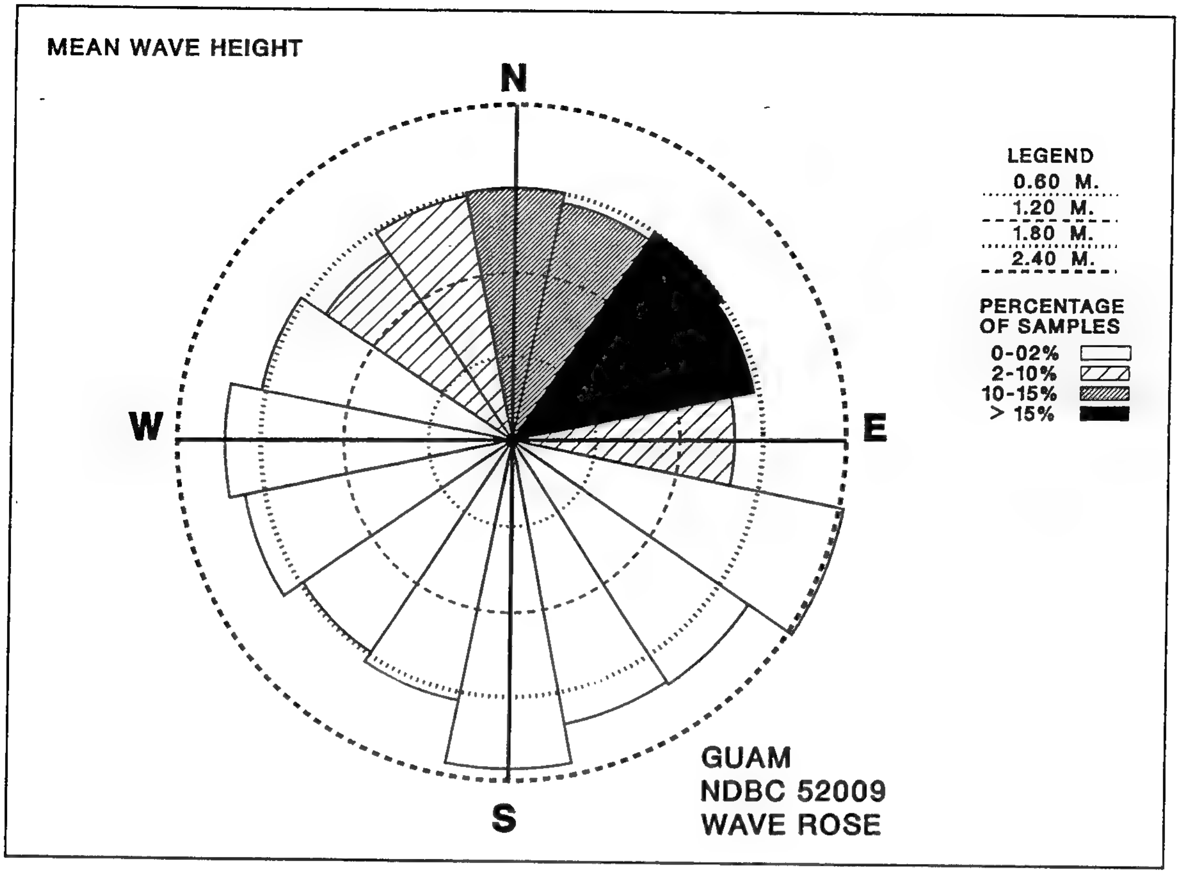


Figure 14. Rose plot of incident wave conditions

indicated by significant wave height) exhibit another unexpected behavior - they tend to increase as the waves propagate shoreward. Additionally, the peak period on the reef flat bears little resemblance to the incident deepwater wave period. In fact, the notion of a decay ratio for the incident wave height is inappropriate; rather, a non-linear energy transformation occurs.

Figure 16 is a pressure time series plot from the gauges at sites 5A, 2B, and 4D that illustrates the transformation process. In relatively deep water at the outer end of the channel (site 5A), the record is that of "normal" swell waves, with periods of about 15 sec. On the reef flat (site 2B), the characteristic nonlinear shape has evolved. A longer harmonic, near 100 sec, can be seen modulating the signal.[1] In the harbor (site 4D) this long wave completely dominates the signal, while the wind waves are effectively blocked.

[1] The 2.5-Hz sampling rate has "stretched" the bottom two plots relative to the first, 1-Hz-sampled plot.

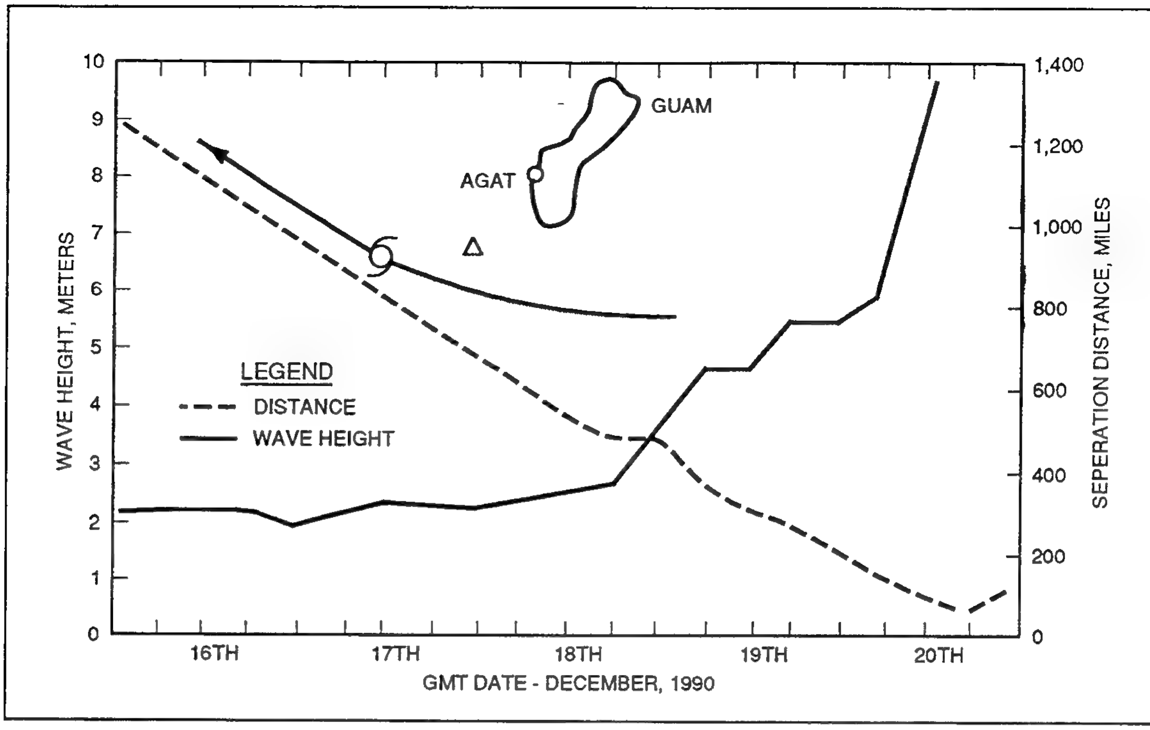


Figure 15. Typhoon Russ; path and observations

Table 2
Summary of Reef Flat Wave Transmission Events

Date-m/d/yr time-GMT	Significant Wave height (m) Peak Period (sec)				Depth (m)
	1B	2A	2B	4A	
10/16/92 0200	1.77 12.5	0.26 102	0.36 102	0.29 205	0.9
10/16/92 0600	1.83 12.5	0.21 205	0.31 205	0.21 205	0.7
11/23/92 0600		0.26 68	0.45 68	0.51 205	0.8
11/23/92 1500	5.13 12.5				
11/24/92 0600	4.26 11.1	0.26 205	0.42 102		0.8
11/24/92 0800	4.52 11.1	0.26 205	0.45 205		0.9
08/06/93 1600	3.95 12.5			0.86 205	1.2
08/07/93 0200	3.51 12.5			0.79 205	1.1
08/07/93 0600	2.85 11.1			0.47 205	0.8
08/07/93 1400	3.05 12.5			0.71 205	1.2
08/07/93 2200	2.94 12.5			0.51 205	0.9

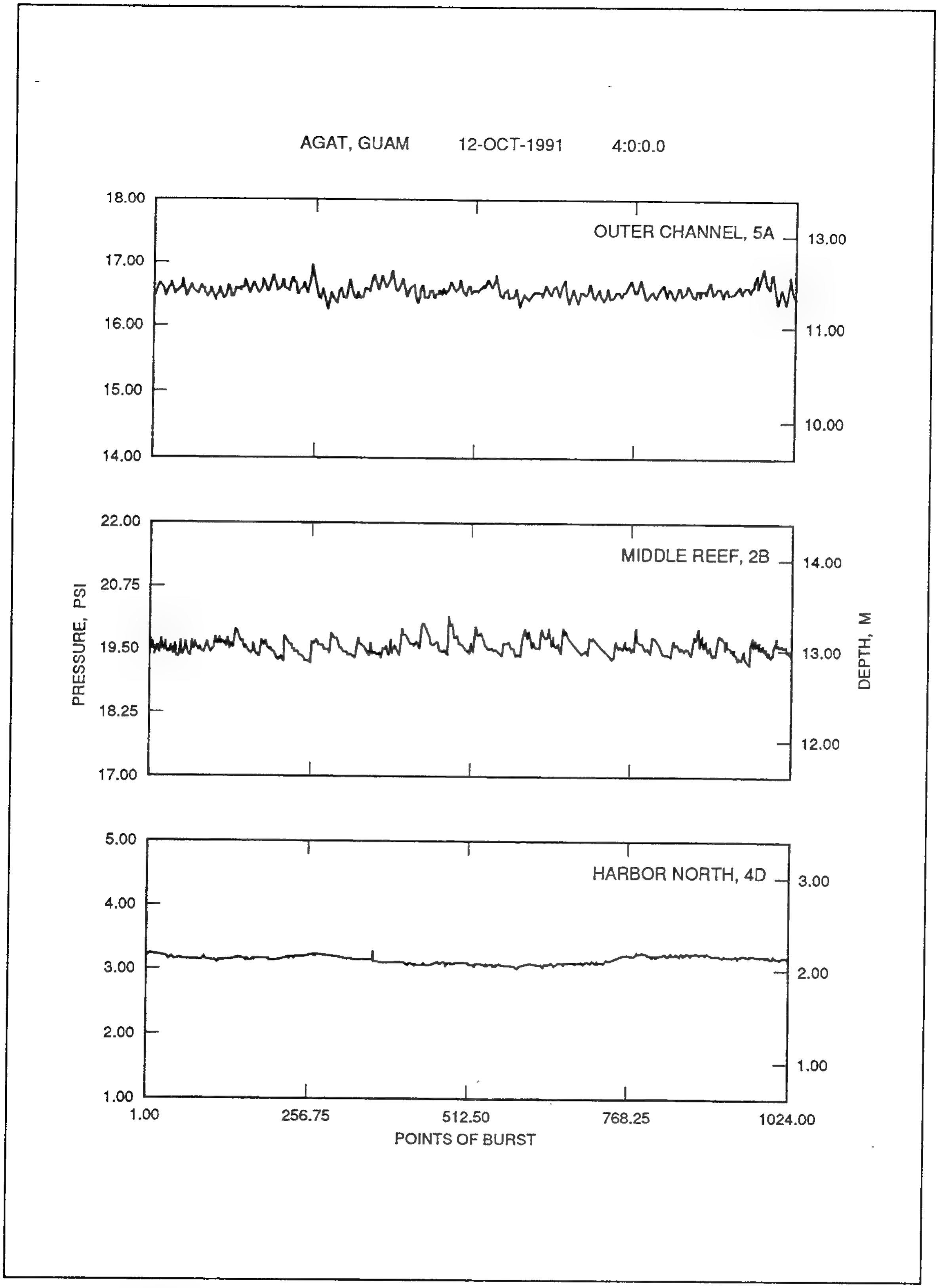


Figure 16. Wave transformation; pressure time series

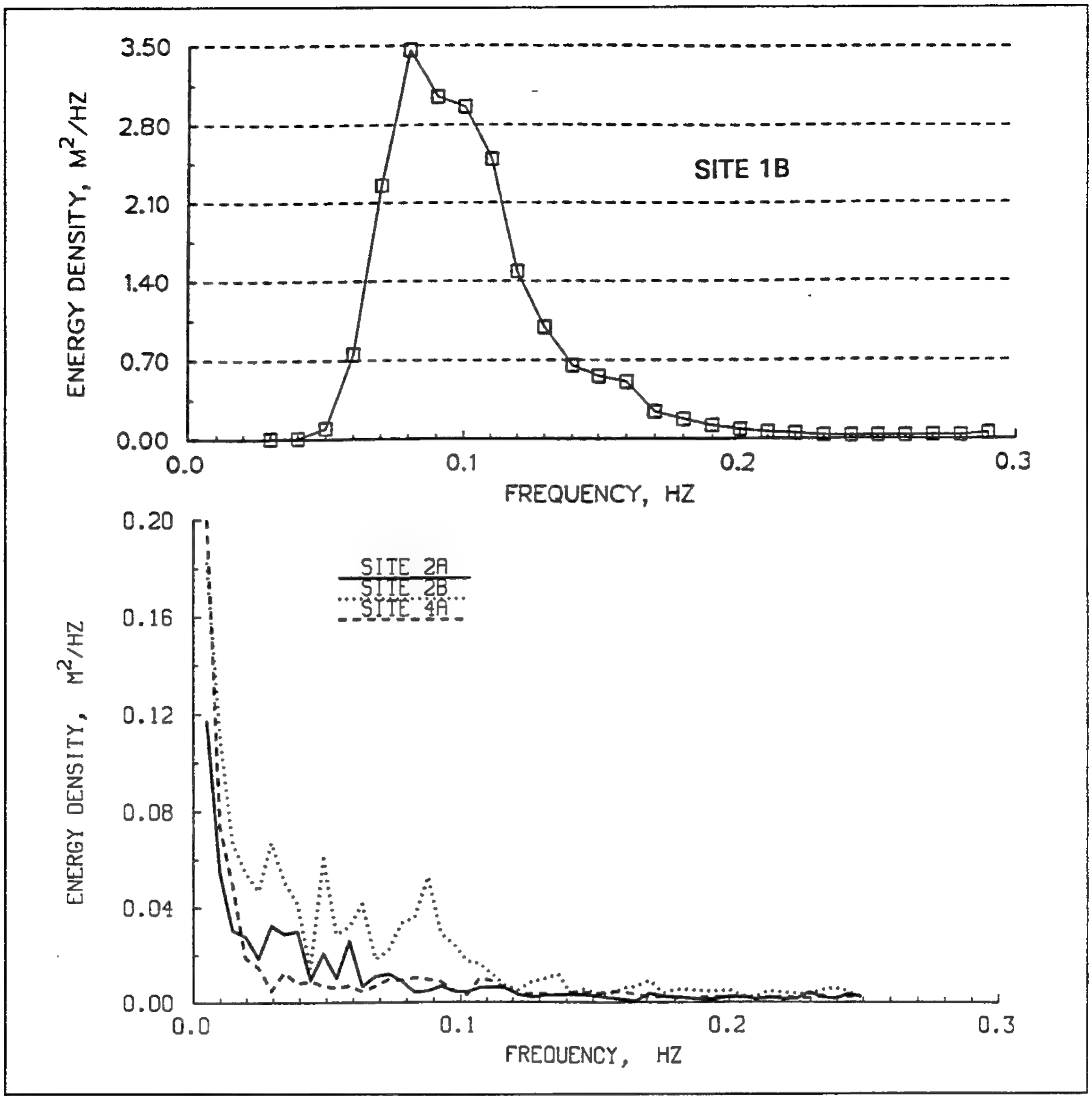


Figure 17. Energy spectra for sites 1B (a) and 2A, 2B, and 4A (b) on 10/16/92 @ 0600 hr

Figure 17a is the energy spectrum from site 1B at 0600 hr on 16 October 1992, which is typical for fully developed wave conditions in deep water. Incident significant wave height was about 1.8 m. Underneath (Figure 17b) are the spectra from the reef gauges, showing the dramatic increase in low-frequency content moving shoreward. The aforementioned low frequency limit on the reef flat sensors precludes accurate identification of the peak period, but it is clearly more than 100 sec. The 12-sec (0.08-Hz) offshore peak is not apparent at site 2A, shows as a secondary peak at site 2B, and is barely visible at site 4A. This trend is typical of all cases examined, as further illustrated in Figures 18a and 18b, for the conditions at 1600 hr on 6 August 1993.

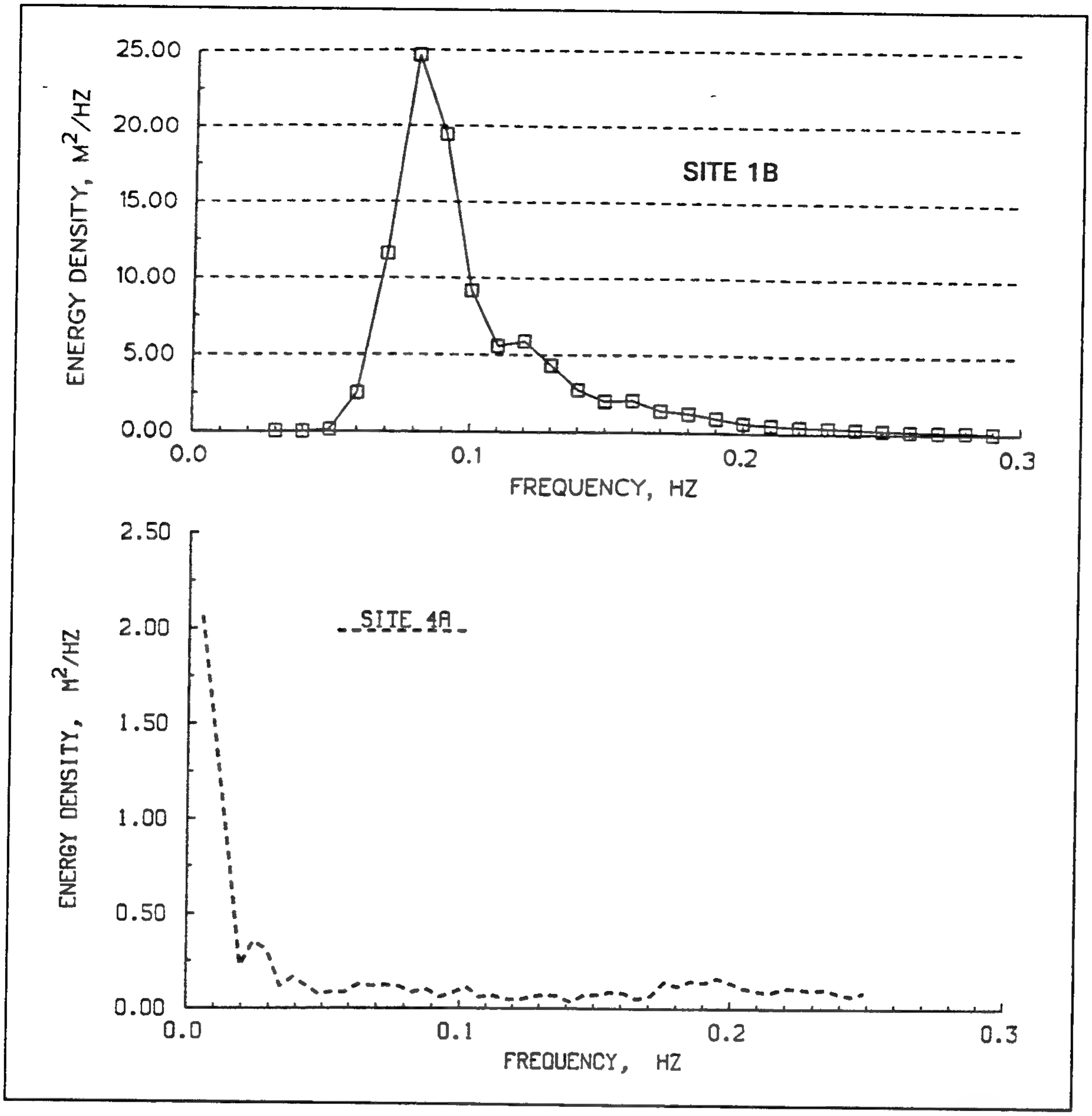


Figure 18. Energy spectra for sites 1B (a) and 4A (b) on 8/06/93 @ 1600 hr

Note the scale change relative to the previous figure; incident significant wave height is near 4 m in this case.

c. *Design waves and surge levels behind coral reefs.* No data were obtained by the onshore system during extreme - or even moderately severe - wave conditions; this objective was not met. The water levels recovered during typhoons Omar amd Brian were those of a leeward shore, so no dramatic surge occurred. Figure 19 shows the depth time series for the gage at site 2-M for the landfall of Omar and the four-day period during and after the landfall of Brian. The mean water level on the high tide (mhw) after Omar's passage is perhaps 1/2 m above the previous mhw. Superimposed high-frequency oscillations

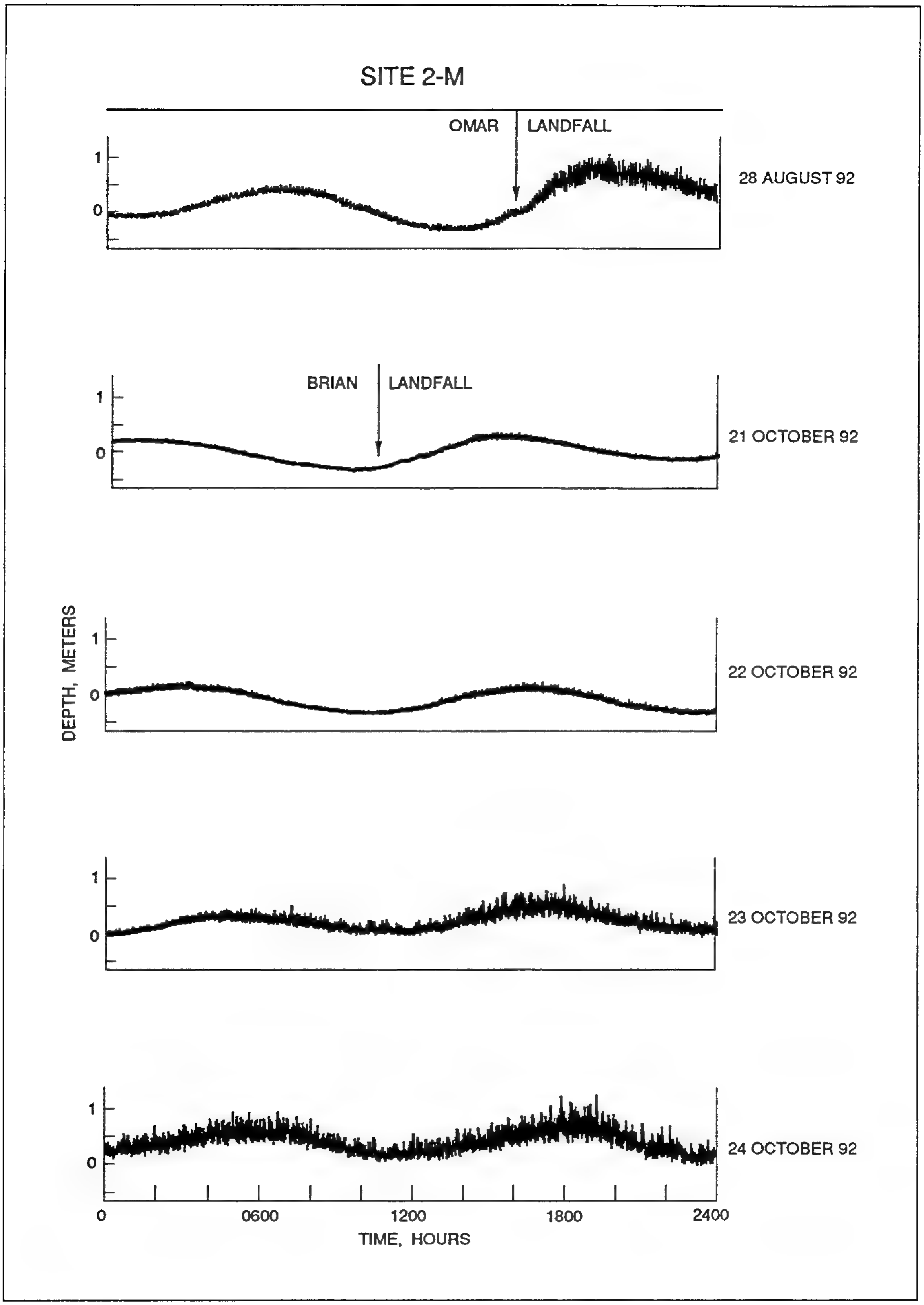


Figure 19. Pressure time series at site 2-M for typhoons Omar and Brian

(i.e., relatively high when compared to tides, but low relative to wind waves) are about the same magnitude as the surge. This indicates that design water levels for the reef flat should include both these long wave motions and the average water levels.

d. *Validation of the HARBS model.* Insufficient data were obtained from the sensors inside the harbor to provide validation of HARBS. Because the model was run for wind waves between 8 and 20 sec, the observed long-wave phenomenon was not modeled.

e. *Wave transformation down steep-sided channels.* Simultaneous operation of sensors 5A and 5B was always during low wave conditions. Insufficient data were obtained to meet this objective for waves of engineering significance.

f. *Site inspections.* The reef flat is not actually flat on the human scale, but pockmarked with sand-filled holes and cracks ranging from centimeters to meters in scale. A thin veneer of sand covered much of the higher surfaces. A dive inspection revealed that the bottom of the entrance channel is thick (over 1 m) sand, as is the bottom of numerous fissures further offshore. These fissures, on the order of 5 m deep and some tens of meters across, run for hundreds of meters in a generally cross-shore direction offshore of the reef face to the top of a near vertical wall that begins around - 30 m. Some 30 m further down the wall, a massive wedge of sand begins its steep (about 1 on 1) descent downward and offshore.

Though the breakwater is classified as a rubble mound, the shallow depths and clarity of the water allowed it to be built essentially as a laid-up structure. The armor stones were individually placed and fitted, often after repeated trials and hand shaping with chisels. The result is a surface that could accommodate the average sedan (see Figure 20). The only discrepancy observed in the inspections occurred on the northern end of the revetted shoreline, at the northwest corner of the harbor. A stone at the toe of the revetment in about 1 m of water, estimated to weigh about 200 kg, was displaced about 1/2 m seaward some time between harbor construction and September 1990. No other damage was observed over the course of the study. No effects were observed on adjacent shorelines.

The one significant change in the project was in the boat basin itself. Between the completion of the breakwater and completion of the marina facilities in 1990, approximately 1,000 cu m of sediments accumulated in the northern end of the boat basin. Depths were reduced to about a meter in places, making those slips unusable for all but outboard vessels.

g. *Wave-induced circulation on the reef flat.* A "dry run" of the episodic measurement approach was conducted on 7 August 1992 during calm

Figure 20. Breakwater surface

conditions to test the instruments and practice the deployment technique. For Typhoon Omar, pressure sensors were deployed at Sites 2-M, 3-O, and 4-M (see Figure 11) for a period of 5 days beginning on 27 August. Some current data were collected on the 27th, the day before the typhoon hit, but the velocities were too small to be reliably measured.

Two pressure sensors were deployed (at Sites 2-M and 3-O) on October 20 through 24 for Typhoon Brian. Currents were measured on the 20th (before the storm's arrival) but were again too small to be reliably measured. On 23 October, 2 days after the storm passage, currents on the order of 30 cm/sec were measured, when waves from the departing Brian, combined with a more distant Typhoon Colleen, were over 3 m. The solitary, relatively weak measured current contrasts sharply with a verbal report of a "ripping 15 mph" current in the harbor during the peak of Typhoon Guy. Unfortunately, no pressure gages or current meters were deployed for Typhoon Guy to corroborate the observation.

Measurement of significant currents on the reef was not successful, but the reef oscillations associated with them were (see Figure 19). Figure 21 is a 1-hr "blow-up" of the oscillations at Sites 2-M and 3-O at 1800 on 25 October. Components approaching 1/2 m in height are obvious at periods ranging from under a minute to several minutes.

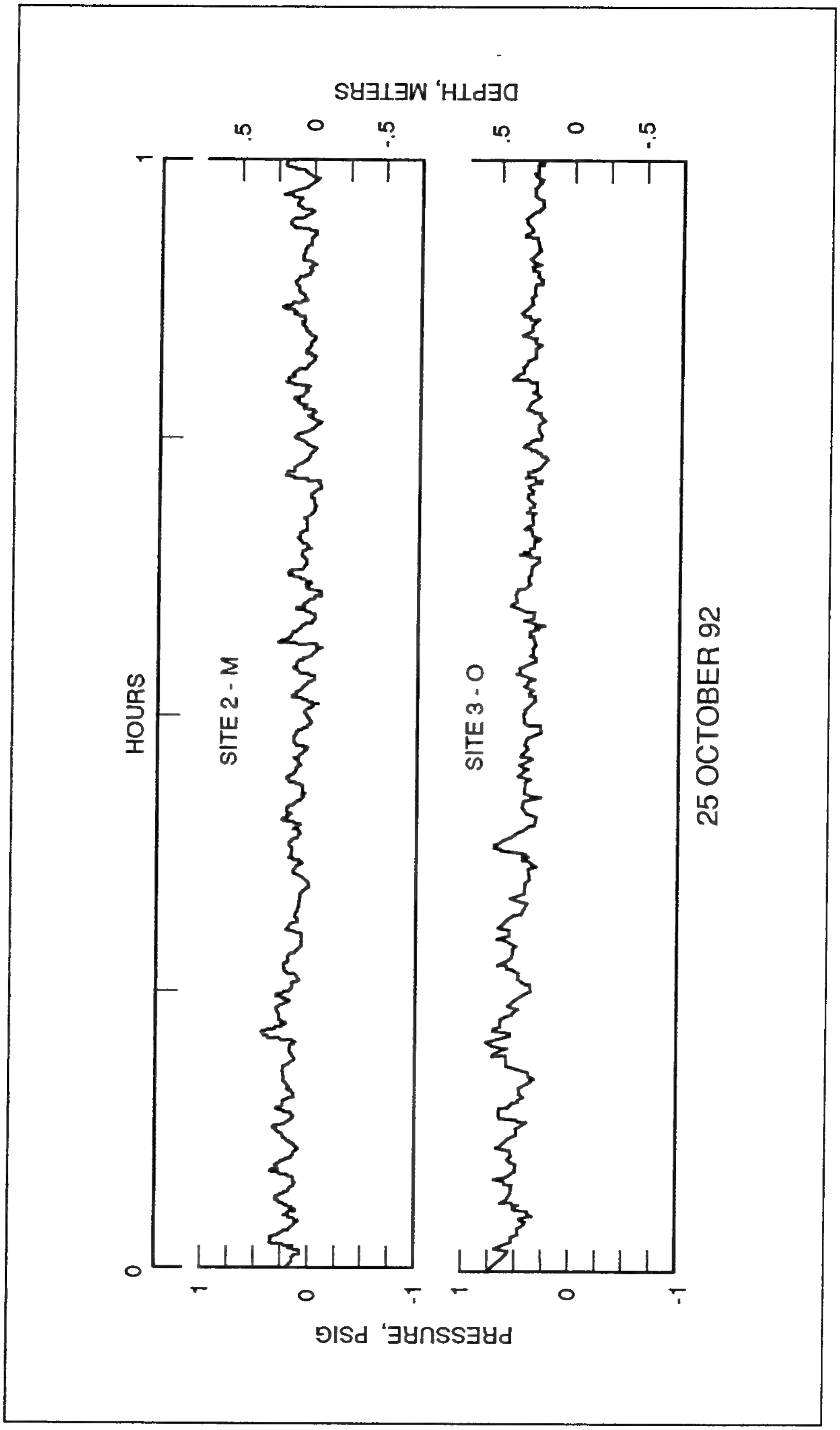


Figure 21. One-hour "blow-up" of oscillations at Sites 2-M and 3-O, 25 October

5 Discussion

Some of the quantitative objectives of the study were not met because of the lack of measured data during the rare high-energy events and because assumptions about the nature of the wave energy on reef flats proved wrong. However, observations have resulted in valuable qualitative information that should be considered when planning or designing projects in a similar environment.

There is no indication that *wind* waves on a reef flat will exceed the depth-limited breaking criteria used for sloping beaches. The highest wave height to water depth ratio in Table 2 is about 0.72, slightly lower than the 0.78 breaking wave criteria used in design. However, this energy-based significant wave height includes all of the low-frequency energy as well, and is really associated with the seiche amplitudes. The height of the highest wind waves on the reef flat, a figure needed in calculating stone stability, will probably not even exceed one half the water depth, as long as the water depths are shallow. However, as the water depth increases due to surge, the breaking wave height limit will increase. Without verification of a lower breaking limit under typhoon conditions, the standard depth-limited criteria should be retained for design.

No measurement of surge levels during typhoons approaching from the west was obtained that exceeded the initial design estimate of 1.4 m. Estimates of surge from measurements or models of planar beaches are unlikely to apply. Some information on the wave-induced setup is available from laboratory studies reported in Smith (1993). Data from a two-dimensional physical model study of a reef-type profile are compared to numerical predictions of wave height and water level behind the reef. Setup on the reef flat on the order of 10 percent of the incident wave height was predicted for cases typified by the prototype measurements in Table 2. (Though the reef profile modeled is described as representing Agat Harbor, the bathymetry is dissimilar enough from the prototype that detailed comparisons with data in this report are not likely to be productive.) For the 9.8-m incident waves measured during Typhoon Russ, wave setup of about 1 m is likely, in addition to atmospheric effects. In any case, wind waves propagating shoreward are not the only, and maybe not even the predominant, environmental loading for structures on reef flats. The physical model simulated the low-frequency energy observed on the reef flat, and predicted heights on the order of 1/4 to

1/2 the incident wind wave height. Forces on structures due to the currents associated with these long waves should be considered as well as wave forces.

A candidate description of the long waves is a seiche of the open-ended basin represented by the continuous stretch of reef flat between the prominent point (Nimitz Beach) in the south and the small islands at Gaan Point in the north. Figure 2 provides an aerial view of this feature. If it is approximated as a rectangular basin length × width × height, with dimensions 600 m × 2,400 m × 1 m , the equation for the seiche periods (neglecting friction) is

$$T = 4\left[gh\left(\frac{4m^2}{w^2} + \frac{(2n - 1)^2}{\ell^2}\right)\right]^{-1/2} \tag{3}$$

where n and m are the modes of oscillation for the cross and longshore dimensions, respectively, and g is gravity. Table 3 gives the first two modes for the cross and longshore oscillations, independently and combined.

Table 3
Seiche Modes for a Rectangular Basin

n	m	T (sec)
1	0	766
0	1	1533
2	0	255
0	2	766
1	1	685
2	1	252
1	2	542
2	2	242

Note that the first crosshore and second alongshore modes coincide. Friction effects would tend to reduce the seiche periods somewhat, so an oscillation on the order of several to ten minutes, as observed, could be predicted to occur. This is within the range commonly associated with surf beats on other coasts. While no measurements or observations are available to verify their presence in the incident waves, surf beats are most likely the forcing mechanism for the low-frequency energy on the reef flat.

The peak magnitude of the currents associated with these oscillations is

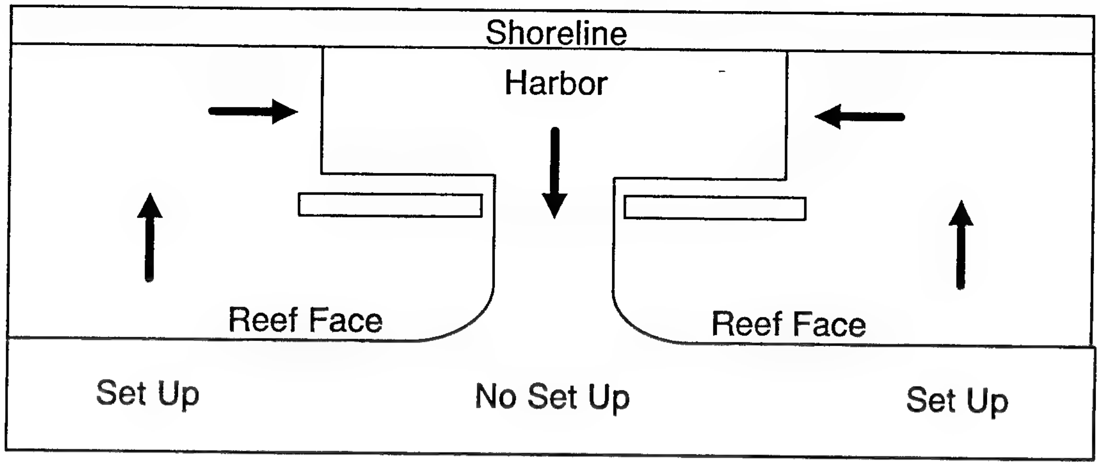
$$v = \frac{H}{2}\sqrt{\frac{g}{h}} \tag{4}$$

or on the order of 1 m/sec for seiche amplitudes on the order of 30 cm. While these are significant, they are less than the observed velocities. In addition, seiche oscillations would be periodic, reversing direction each cycle. Another mechanism must account for the pulsing currents.

The qualitative description of the wind waves propagating across the flat can be shown to be consistent with quantitative estimates. If the reef flat water depth, h, is assumed to be 1 m, a 30 cm/ 10 sec wave has an Ursell number of about 300, and is best described with cnoidal theory. The square of the modulus of the elliptic integral k^2 is about $1 - 10^{-5}$, or very near to unity, at which cnoidal theory reduces to solitary wave theory (*Shore Protection Manual* 1977). Shoreward mass transport per unit crest width for a solitary wave is $[(16/3)\ h^3\ H]^{1/2}$, or about 1.3 m^3/m. For the reef flat dimensions above, this amounts to over 300 m^3/sec moving shoreward.

The shortest path (hydraulically) for the return flow to take is toward the ends of the reef flat, where breaking and setup are not occurring. Since the harbor is connected to deep water by the entrance channel, the low water level is brought conveniently close - from the return flow's perspective. If just one third of the return flow takes this "short-cut" through the harbor and entrance channel back to sea, velocities across the 100-m-wide opening would be on the order of 1 m/sec. This is sufficient to balance the out-of-phase flow from the seiche, and double the in-phase flow, resulting in a pulsing flow of up to around 4 knots. This is a little less than observed, but no allowance has been made for the setup return flow. Figure 22 schematically illustrates the circulation mechanism hypothesized. Highest velocities would occur where the gradient is steepest, which is near the shoreward side of the harbor basin. This pattern could explain the displacement of the toe stone at the northwest corner of the basin, an area exposed to the highest velocity currents flowing into the harbor.

The sediment that entered the harbor came from the veneer of sand that is evident in many places overlaying the old coral on the reef flat. It was transported there by the currents flowing through the harbor, which acts as an effective settling basin. Given the evidence of significant offshore sediment transport through the natural pathways, this process will continue for the current harbor configuration. Since the transport is episodic, it is impossible to predict the short-term rate of influx. If it is a persistent problem, alternative geometries that would reduce influx of sediment while maintaining the desirable flushing characteristics could be investigated.



Input: $T_{\text{set up}} = f(\text{surf beat})$

Response: $T_{\text{seiche}} = f(\text{reef dimensions})$

Figure 22. Schematic representation of reef flat circulation/oscillation

6 Conclusions

The following conclusions were reached as a result of this study:

a. With the exception of the NDBC buoy located offshore, most data recovered from this monitoring effort represent mild conditions. The buoy recorded waves near 10 m before failing during Typhoon Russ.

b. Wind waves dissipate most of their energy in breaking at the reef face. Wave energy propagates across reef flats as bores, moving water shoreward that returns seaward through breaks in the reef face. Agat Harbor and its entrance channel provide such a pathway.

c. Wave heights on the reef flat do not increase appreciably as wave height offshore increases, but the amplitude of seiche of the entire reef flat is affected by incident energy. It is probable that wave groups (surf beats) with periods near the principal seiche modes of a reef flat will induce harmonic coupling. For this system, coupling can occur at periods on the order of several to ten minutes.

d. The combination of seiche, return flow from wave setup, and mass transport of bore-like waves can result in large currents running parallel to shore. For structures located on the reef flat, forces due to the resulting currents can be of larger magnitude than forces due to the wind waves themselves. Currents on the order of 3 m/sec were observed visually under moderately rough wave conditions. This observation is consistent with calculations of currents due to combined seiche and solitary waves 30 cm in height. Currents are probably responsible for displacement of one stone at the toe of the structure.

e. Typhoon surge levels were not measured, but are likely to be a meter or more, based on model data.

f. It is difficult to extrapolate these results to more extreme events. During a typhoon, wind shear on the water would play an important role, but the approach angle would determine whether this adds or cancels the current. A high surge may increase seiche amplitudes, but tend to linearize waves propagating on the flat, reducing mass transport. The design storm may well be one that passes eastward of the island on a

northwesterly track, bringing little surge but strong northwesterly wind and swell <u>after it passes</u> the island. Under these conditions, it is not unreasonable to anticipate currents exceeding 5 m/sec on the reef flat.

g. The detached breakwater design promotes flushing of the harbor, but can result in significant influx of sediment during high-current events.

References

Boc, S. J., and McGehee, D. (1989). "Agat Small Boat Harbor, Guam - Monitoring Plan." *Proceedings, Coastal Zone* '89. American Society of Civil Engineers, Charleston, SC.

Chen, H. S., and Houston, J. R. (1986). "Calculation of water oscillations in coastal harbors - HARBS and HARBD user's manual," Instruction Report CERC 86-7, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Earle, M. D., McGehee, D., and Tubman, M. (1996). "Field wave gaging program, wave data analysis standard," Instruction Report CERC-95-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Farrar, P. D., and Chen, H. S. (1987). "Wave response of the proposed harbor at Agat, Guam: Numerical model investigation," Technical Report CERC-87-4, U.S. Army Engineer Waterways Station, Vicksburg, MS.

Longuet-Higgins, M. S., Cartwright, D. E., and Smith, N. D. (1963). "Observations of the directional spectrum of sea waves using the motions of a floating buoy," *Ocean Wave Spectra*, 111-36.

Shore protection manual. (1977). 3rd ed., 2 Vol, U.S. Army Engineer Waterways Experiment Station, U.S. Government Printing Office, Washington, DC.

Smith, J. M. "Nearshore wave breaking and decay," Technical Report CERC-93-11, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Steele, K. E., Wang, D. W., Teng, C., and Lang, N. C. (1990). "Directional wave measurements with NDBC 3-meter discus buoys," 1804-01.05, U.S. Department of Commerce, National Data Buoy Center, Stennis Space Center, MS.

U.S. Army Engineer District, Honolulu. (1981). "Final Detailed Project Report and Environmental Statement; Agat Small Boat Harbor, Territory of Guam," Honolulu, HI.

Appendix A
Work Description and Reports for Contracted Current Measurements

SCOPE OF WORK

I. TITLE - Modification to Delivery Order #33 DACW39-88-D-0059
Study of Currents at Agat Harbor, Guam.

II. DESCRIPTION:

The Monitoring Completed Coastal Projects (MCCP) work at Agat Harbor, Guam, includes monitoring the currents within the harbor and entrance channel and on the adjacent back reef. Under normal wave conditions these currents are small. However, storm waves transport large amounts of water across the reef crest and into the backreef area. Under these conditions, the harbor and entrance channel can act as a rip channel for this water to return to the open sea. The large currents produced in and near the harbor can lead to problems with moored vessels and with harbor sedimentation. Thus, an understanding of this process is needed to alleviate problems at this specific harbor and to supply general design guidance for future harbors in this type of environment. In addition, the proposed current study will synergistically support the long term wave monitoring program already underway at this location as another part of this MCCP project.

III. SPECIFIC DUTIES:

The contractor will plan and execute a series of deployments to survey the currents and water elevations in the back reef area adjacent to Agat Harbor Guam during periods of high waves. (In previous versions of this Scope of Work, this effort was labeled TASK 2.) Each deployment will consist of a field team installing water level gauges and making Lagrangian and Eulerian current measurements at appropriate locations on the back reef. Each of these three parts is discussed in detail below.

Six deployments are proposed, if appropriate conditions exist, during the period August 1992 - January 1993. The first will be a "dry run" deployment during typical calm wave conditions. This will be useful as a training exercise for personnel, as a source of baseline current data, and as a test of the adequacy of the measurement plan. This deployment will occur during the first week of August, 1992, when WES personnel are at Agat.

Currents on the backreef and through the harbor are expected to vary primarily as a function of offshore wave height and tidal stage (water elevation over the reef crest). Thus, it is likely that a major wave event will provide multiple opportunities for deployment. The five main deployments should cover as broad a range of these two variables as possible. A decision to deploy should be based upon threshold current speeds over the backreef near the harbor significantly in excess of 25 cm/sec and/or visually estimated RMS breaking wave heights significantly in excess of 2 meters on the reef crest. Additionally, the decision to deploy may be made in consultation with WES personnel.

a) Before each of the current deployments discussed below, the contractor will install, activate, and synchronize three Sea Data TDR water level gauges on permanent mountings in the backreef area near Agat. Twelve to thirty-six hours later (possibly longer) and after the current deployments, he will retrieve the gauges and dump the data. The data will be quickly examined to determine if the meters are functioning properly. If not, the

situation will be rapidly reported to WES personnel. WES will supply the three TDR gauges, the mounting hardware, batteries, a cable from the TDR with a RS-232 connector to a PC to dump the data, and PC software. In addition, during the first week of August, WES personnel will permanently install and survey the TDR mounting brackets on the backreef and will train the contractor's personnel in the use of the equipment. The contractor will supply a PC computer to receive the data, plus the field team.

Depending upon wave and weather conditions, WES personnel may request that these gauges be installed, retrieved, and the data dumped up to two additional times (for a total of 8 times) when the current measurement deployments discussed below are not made.

There is concern that theft or vandalism may occur to these gauges. The contractor should take reasonable precautions against this, where possible. For example, planning to have the gauges deployed during the night, during weekdays, during inclement weather, and/or while the contractor is on the site should all help to reduce the risk.

b) At each deployment the contractor will supply sufficient Lagrangian drifters to determine the general flow patterns across the reef (speed and direction). It is expected that these will be tracked manually, without the use of sophisticated survey equipment. The primary information to be gained is a qualitative understanding of the longshore distance of the harbor's influence of the current patterns on the reef. For each deployment this effort is expected to take 1-2 hours of field time to complete.

c) At each deployment Eulerian current measurements will be made at each of approximately 10 - 15 pre-established locations on the reef flat. These measurements will be manually read from hand-held (WES supplied) instruments over a 3-5 minute interval. Current direction, water depth, wind speed, time, and comments will also be noted. For each deployment this effort is expected to take approximately one hour of field time to complete and should occur immediately before or after (or simultaneously with) the Lagrangian measurements.

IV. REQUIRED EQUIPMENT:

WES Supplied

1. Three Sea Data TDR gauges with the mounting hardware, batteries, cable with a RS-232 connector, and PC software to receive the TDR data.
2. Five manually operated current meters with water depth gauges.
3. Five manually operated anemometers.

Contractor Supplied

1. Field deployment equipment: eg. waterproof watches, compasses, slates, Lagrangian current drifters, etc.
2. Data collection and reduction equipment, including a PC computer.
3. All other equipment necessary to complete task.

V. REQUIRED PERSONNEL:

WES Supplied

1. Personnel for training contractor's team members.
2. Dive inspector if required.

Contractor Supplied

1. Field data collection team.
2. All other personnel necessary to complete task.

VI. SPECIFIC DELIVERABLES:

1. A data package for each deployment shall be produced. (Reports for deployments that occur in rapid succession may be combined.) The TDR water level data will be presented in a series of ASCII readable files containing calibrated time series. Each data file shall have a header that includes the start and end date and time, station, calibration factors, amount of data, comments, etc. Ancillary information will include a discussion of the procedures used for calibration, for error checking, and for handling errors and missing data. Any massaging (i.e., nonstandard processing) of data will be appropriately documented. In addition to the data files, time series plots of the water elevation (several days per page) will be produced for each gauge. These plots will be used by WES personnel to help choose the appropriate data segments for further analysis. Lagrangian current measurements will be displayed on maps and shall indicate the general circulation patterns of the reef flat area. Dates, times, and general current speeds will be indicated. Eulerian current measurements will be in ASCII computer files that indicate the date, time, station, current speeds and direction, wind speed and direction, water depths, comments, etc. Each data package shall also include a general discussion of the deployment.

2. The contractor shall consult with and keep WES personnel informed concerning schedules, status of instruments, and problems that arise.

VII. DELIVERY ORDER SCHEDULE:

1. Eight (max) deployment reports: 4 weeks after each deployment.
2. Informal consultation: as appropriate.

VIII. CONTRACT DURATION:

1. Field Work: August 1992 - January 1993.
2. Deployment Reports: August 1992 - February 1993.

SCOPE OF WORK

I. TITLE - Study of Currents at Agat Harbor, Guam.

II. DESCRIPTION:

The Monitoring Completed Coastal Projects (MCCP) work at Agat Harbor, Guam, includes monitoring the currents within the harbor and entrance channel and on the adjacent back reef. Under normal wave conditions these currents are small. However, large waves transport large amounts of water across the reef crest and into the backreef area. Under these conditions, which most frequently occur during typhoon season but not necessarily during a typhoon landfall on Guam, the harbor and entrance channel can act as a rip channel for this water to return to the open sea. The large currents produced in and near the harbor can lead to problems with moored vessels and with harbor sedimentation. Thus, an understanding of this process is needed to alleviate problems at this specific harbor and to supply general design guidance for future harbors in this type of environment. In addition, the proposed current study will synergistically support the long term wave monitoring program already underway at this location as another part of this MCCP project.

The study will be similar to the one conducted last year. However, one change is that this year we are attempting to only specify characteristics of the data we need, rather than to specify the data collection procedure. It will be up to the contractor to specify (and implement) the details of the procedure. It is hoped that this approach will decrease costs and lessen the mis-communication problems that plagued last year's effort.

The water level elevation data collected last year with the TDR's have been useful, and water level data from the three stations are to be part of this year's effort. However, last year's Eulerian and Lagrangian current measurements did not contribute significant information, and this portion of the study is to be dropped from this year's effort. In it's place current data is to be collected from one or two stations over the same time frame as the water level data. This will presumably be done by deploying and retrieving self-recording current meters in a manner similar to the water elevation gauges. Additionally, these data must be synchronized to the clock on the wave gauge system at the harbor.

III. SPECIFIC DUTIES:

The contractor will specify the details of a data collection plan to survey the currents and water elevations in the back reef area adjacent to Agat Harbor, Guam during periods of high waves. After acceptance of the plan by WES personnel, the contractor will implement the plan. A maximum of five deployments is anticipated.

The plan will discuss (at least) the following elements.

1. Deployment Decision.
The contractor shall specify the procedure to be used in reaching a decision to mobilize for a deployment. If necessary, additional procedures may be specified once the contractor arrives at the site to reach the final decision of whether the deployment is to proceed.

This was a source of confusion during last year's effort, and should be thoroughly cleared up before this year's effort begins. We are interested in obtaining data during big current events. Our present understanding is that these events usually are associated with (and caused by) big wave events, as explained in the first paragraph above. Thus, a decision to deploy should be based upon a forecast of a big wave event. While a typhoon hitting Guam would certainly be expected to generate a big wave event, deployments should not be restricted to direct hit typhoons. Major storms (most likely typhoons) generally anywhere in the Pacific between Guam and The Philippines (to the west or southwest of Guam) should be expected to generate large waves at Agat, and thus would be candidates for deployments.

Two other factors which should be included in the decision to deploy are the number of deployments already made during the current typhoon season, and whether the wave gauge system is operational. Since the analysis of the currents also includes the use of the wave gauge system data, it is very helpful, but not mandatory, that the wave gauge system be operational during a deployment. Procedures for determining this are discussed below.

The length of the deployment should be based upon the severity of the event, the predicted time of the peak, and logistic constraints of access to the deployment sites. The minimum useful data set is two tidal cycles which should bracket the peak intensity of the event. Typical deployment intervals are expected to be 2 - 5 days.

2. Water Level Elevations.

The contractor shall collect water elevation data at the three stations established last year. We assume that the same TDR's will be used this year as last, however, the contractor is free to recommend a different collection scheme. We will continue to support our TDR's with batteries, replacement gauges (if available), etc. During long deployments (circa 5 days) the TDR's must be set to 10 second sample rates because of data storage limitations. However, if a shorter deployment is forecast (2 1/2 days or less), the sample rate should be increased to 5 second intervals. Selecting a shorter sampling interval should not be done at the risk of missing the peak conditions of the event.

3. Currents.

The contractor shall collect current data at two stations to be established near Agat harbor. The most important station will be on the backreef at the north edge of the harbor in the gap landward of the detached breakwater. The Corps of Engineers has plans to close that gap. After this is done this station should be moved to a location outside and near the northwest corner of the harbor. A second station should be established in the harbor entrance channel. This will be in deeper water. If a procedure cannot be developed to deploy a current meter at this station without the use of divers, this station should be abandoned. We will provide maps which specify these station locations more exactly.

It is assumed that some type of self recording current meter will be deployed at each of these stations. Data should be collected continuously over the same time period as the water elevation data and at the same sample rate (if possible). A meter which collects data on current speed alone, not speed and direction, is acceptable. If direction (even low accuracy direction) can be included for a small additional cost, this would be desirable.

One option for instruments is the General Oceanics (GO) system. The subcontractor on Guam already has five of our portable GO current meters (2031H). We have two readout devices (2035MK4) available. Additional cables, data storage chips, underwater housings, current meter mounts, and communication software would be needed. Potential concerns with the system include a lack of directional information and sampling intervals that are too long.

4. Time Sync.

One oversight last year was that the TDR data was not synchronized with the wave network at Agat harbor (which

operates on GMT). This can be done during the initialization of the meters prior to deployment. Using a PC with a modem (contractor supplied) the wave network VAX workstation at Agat can be called and queried for the time and also for the status of the wave network. A consultant is available on Guam to demonstrate the procedure.

5. Reports.
As last year, a report should be produced for each deployment which discusses the deployment and provides the data. Logs should be kept while personnel are at the site deploying and retrieving the instruments. These should include data on environmental conditions, particularly estimated wind and current speeds and directions. The logs should also discuss the deployment, describing any problems and any other ancillary information of note. Additionally, logs should be kept while personnel are initializing the hardware and downloading the data. Copies of these original notes should be included in the reports.

We are concerned that last year we paid more than expected for the amount of data received. This year we would like to see the contractor's bid broken down into three categories: a) costs associated with developing the plan and getting the system operational, b) costs associated with specific deployments, and c) other costs which can not be assigned to development or a specific deployment. Bills for work done should be clearly broken down into these categories; and if category b), the specific deployment should be listed.

IV. REQUIRED EQUIPMENT:

WES Supplied

1. Three Sea Data TDR gauges with the mounting hardware, batteries, cable with a RS-232 connector, and PC communication software; if necessary.
2. Five GO current meters and two GO readout meters; if necessary.

Contractor Supplied

1. Field deployment equipment as necessary.
2. Data communication and reduction equipment, including a PC computer with modem.
3. Water level gauges and/or current meters as necessary.
4. All other equipment necessary to complete task.

V. REQUIRED PERSONNEL:

WES Supplied

1. VAX consultant.
2. WES personnel (at WES) for consultation.

Contractor Supplied

1. Plan development team.
2. Field data collection team.
3. Data reduction and report writing team.
4. All other personnel necessary to complete task.

VI. SPECIFIC DELIVERABLES:

1. A detailed deployment plan as discussed above shall be produced by the contractor and approved by WES personnel.

2. WES shall be notified when all components are operational and the system is available for deployment.

3. A data package for each deployment shall be produced. (Reports for deployments that occur in rapid succession may be combined.) The data will be presented in a series of ASCII readable files containing calibrated time series. Each data file shall have a header that includes the start and end date and time, station, calibration factors, amount of data, comments, etc. Ancillary information will include a discussion of the procedures used for calibration, for error checking, and for handling errors and missing data. Any massaging (i.e., nonstandard processing) of data will be appropriately documented. In addition to the data files, time series plots will be produced for each gauge.

Each data package shall also include a general discussion of the deployment. with copies of field notes.

4. The contractor shall consult with and keep WES personnel informed concerning schedules, status of instruments, and problems that arise.

VII. DELIVERY ORDER SCHEDULE:

1. Design plan: 3 weeks after task order issue.

2. Instrumentation in working order and available for deployment: 4 weeks after task order issue.

3. Deployment reports: 4 weeks after each deployment.

4. Informal consultation: as appropriate.

VIII. CONTRACT DURATION:
1. Plan development: July 1993 - August 1993.
1. Field Work: August 1993 - January 1994.
2. Deployment Reports: September 1993 - February 1994.

EVANS-HAMILTON, INC.
VICKSBURG OFFICE
3202 WISCONSIN AVE.
VICKSBURG, MISSISSIPPI 39180

TEL.: (601) 638-0646
FAX: (601) 634-0631

TO: Dave King

FROM: Jeanne Simmons

DATE: October 13, 1992

SUBJECT: Delivery Order #33 - Guam Current Study

FILE: 4400.66

SEA DATA TDR GAUGES:

The final data files are on the floppy (Filenames: 2m920827.fin, 3o920827.fin, and 4m920827.fin), but each file is approximately 1.6 megabytes. The three files have been zipped, and you can easily unzip them by transferring PKUNZIP.EXE and TDRFILES.ZIP to a harddrive and typing "PKUNZIP TDRFILES". The only editing done to the data was deleting the bad data at the beginning of each record. Please keep in mind that Station 4-M moved. Due to the shallow water depth and the large waves, it may be very difficult to figure out when the TDR moved. The first page of each file has been included for header information and to give you an idea of the data format. Time series plots for both raw and corrected data are included. The time series plots for the corrected data files are in Attachment A, and the time series plots for the raw data files and the printout of the first page of each file are in Attachment B. The dry run TDR data was not included in these plots. We will include it later, but we do not feel the dry run TDR data will show much because of the very short time period the data was recorded and because the conditions were so calm on the reef flat. (Basically, the time series plot of the dry run TDR data will be a flat line about two inches long.)

To calculate depth, the Saunders and Fofonoff's method was used which can be found in the 1983 Unesco technical papers (Algorithms for computation of fundamental properties of seawater). If you have any suggestions for using other time units in the plots, please let us know.

DROGUE DATA:

The map enclosed in Attachment C contains the drogue data from the first deployment on August 27, 1992. The arrow represent the drogue distance and direction traveled after 2.5 minutes.

No drogue data was collected during the dry run.

EULARIAN CURRENT MEASUREMENTS:

Two tables have been created, one for the dry run and the other for the first deployment which are found in Attachment D. The Standard Speed Rotor Constant of 26,873 was used. The two tables are also on the disk in ASCII format.

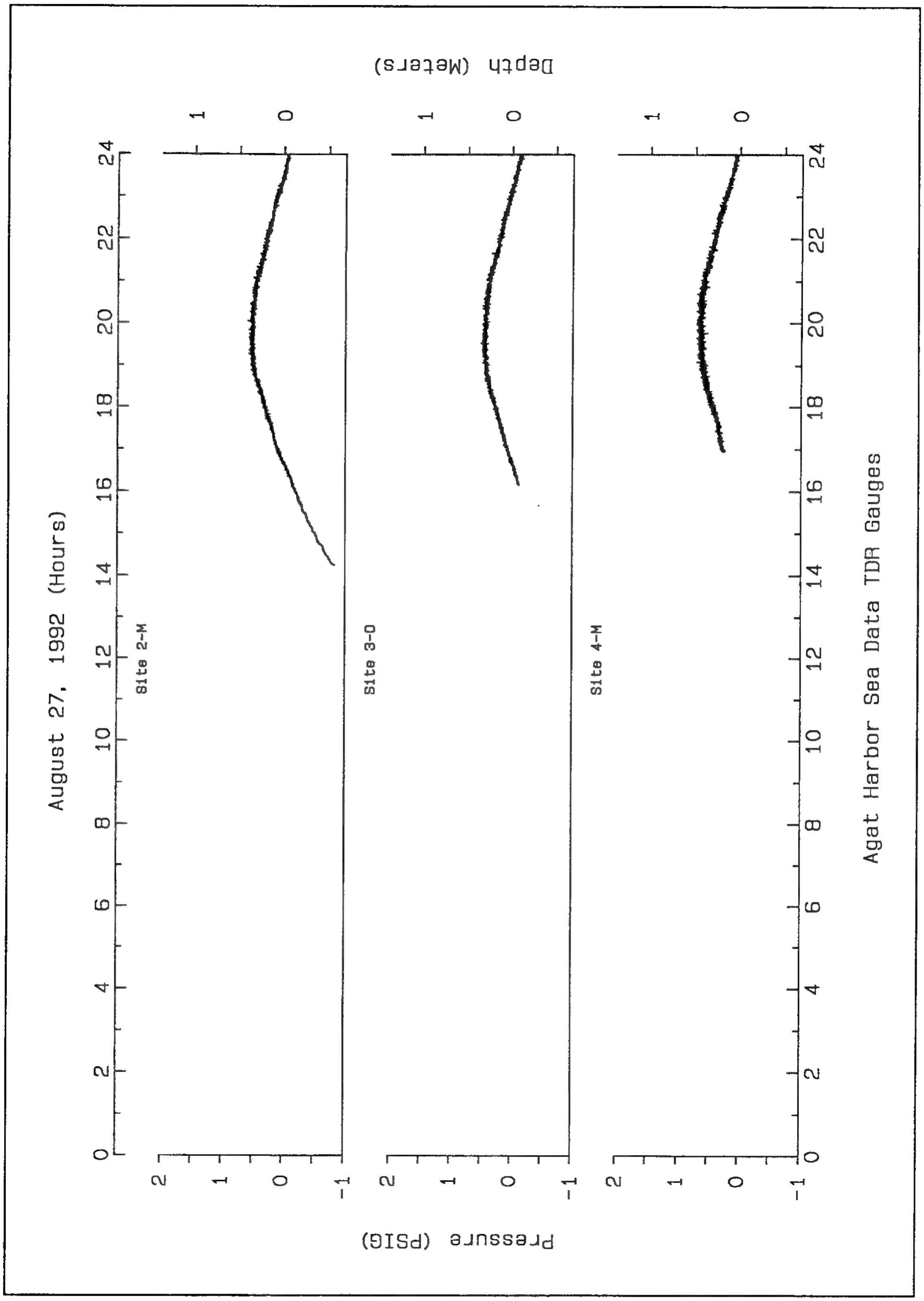
If you have any questions about the enclosed material, please do not hesitate to contact me.

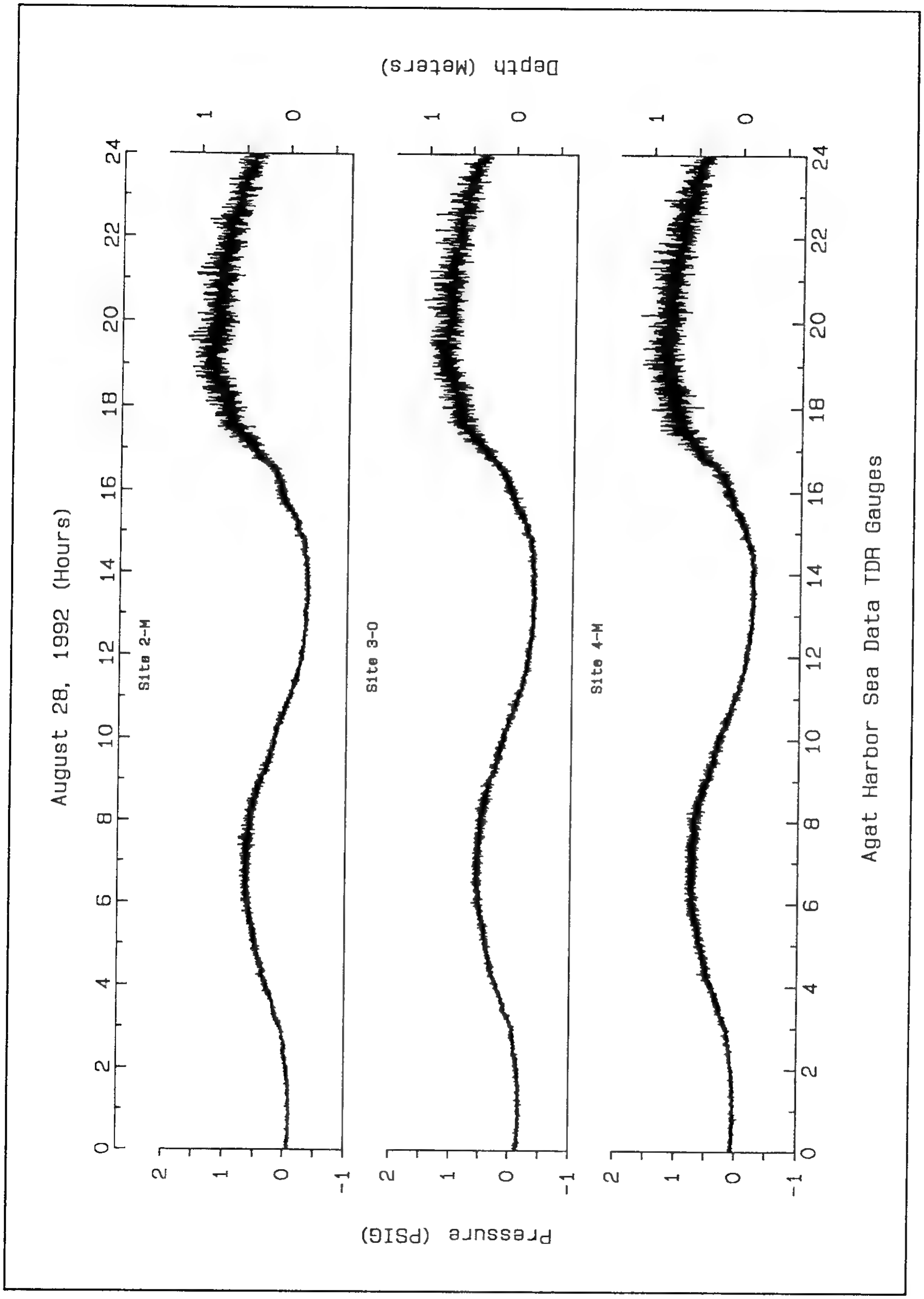
Sincerely,

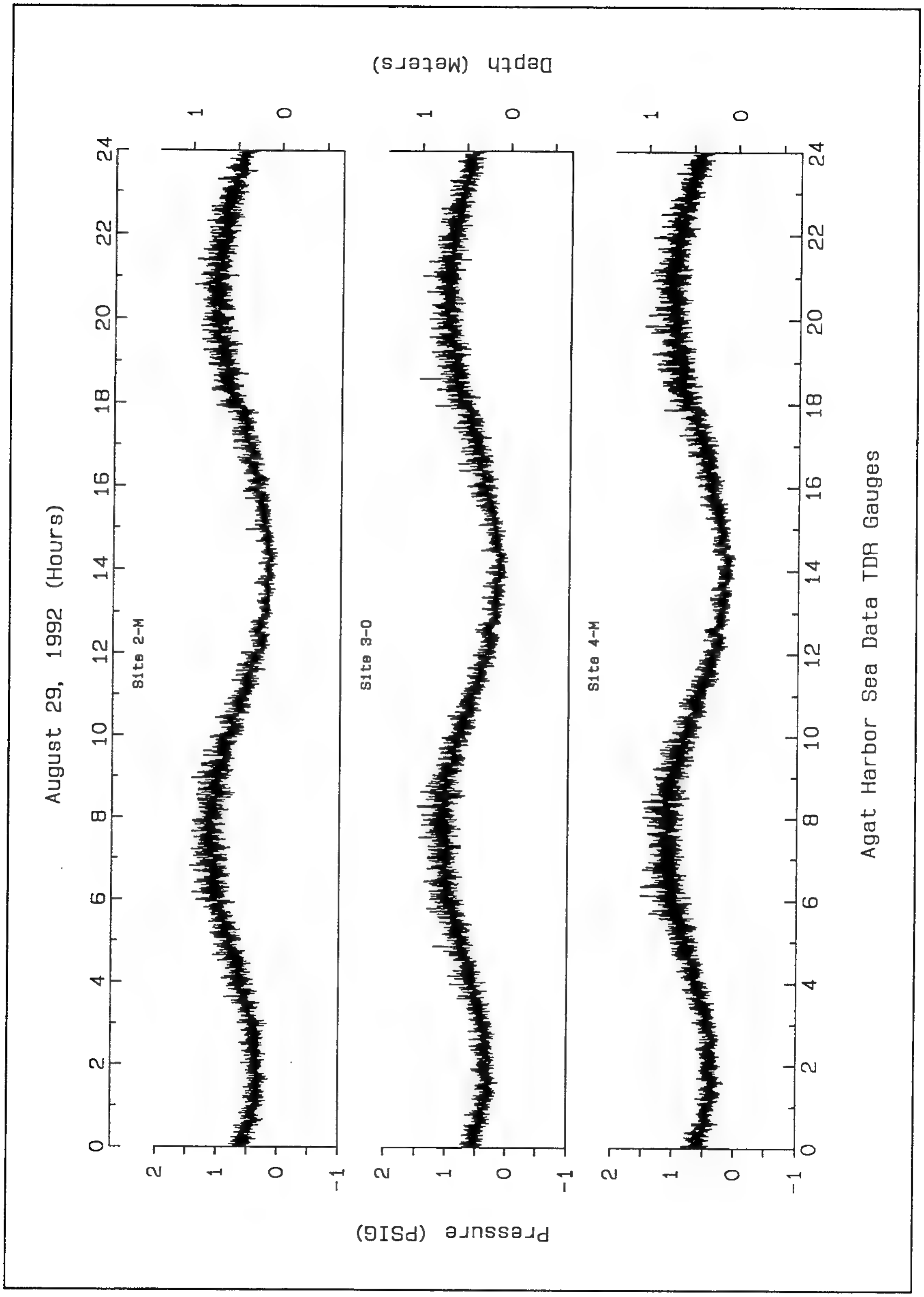
Jeanne Simmons

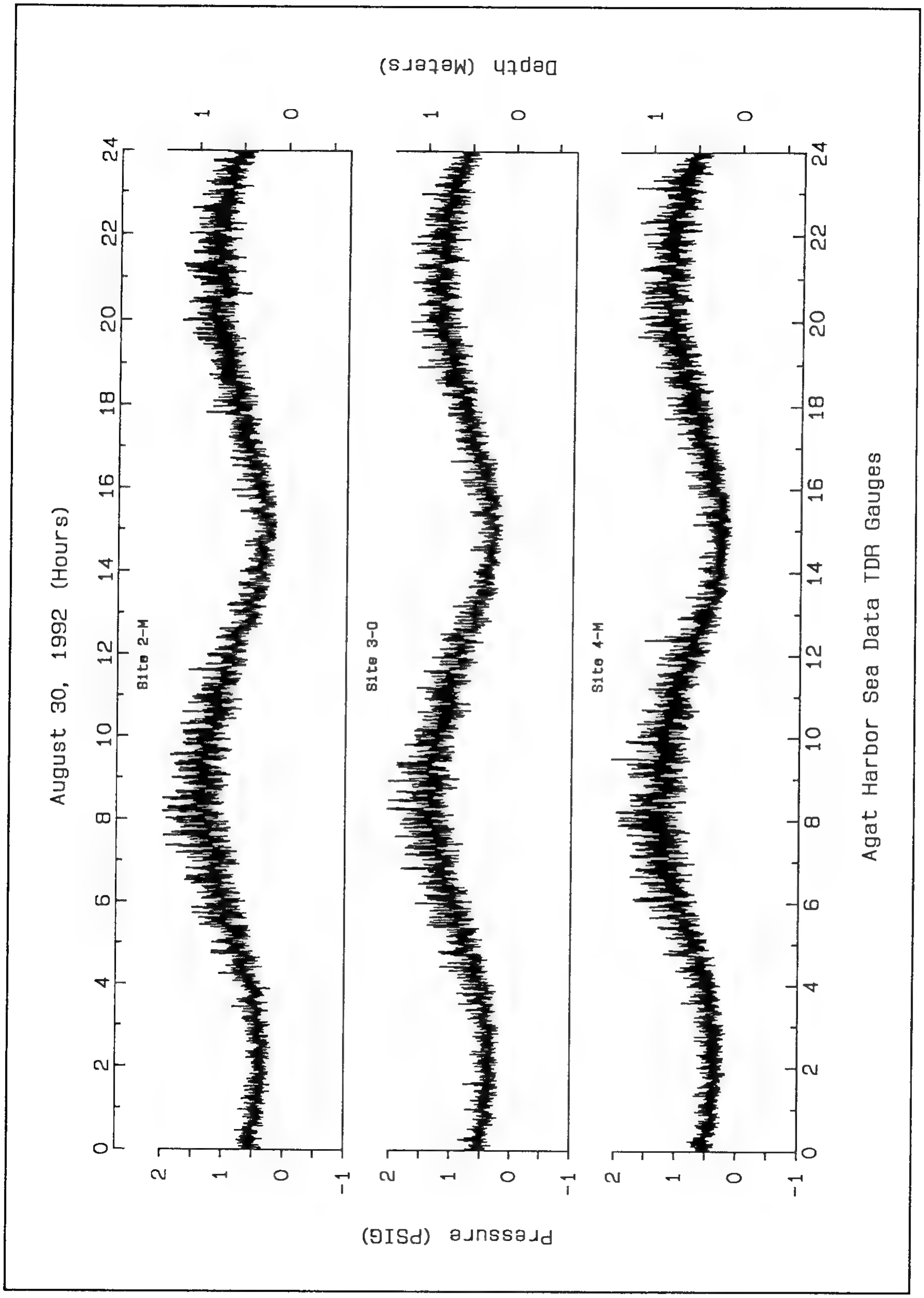
Jeanne Simmons
Oceanographer

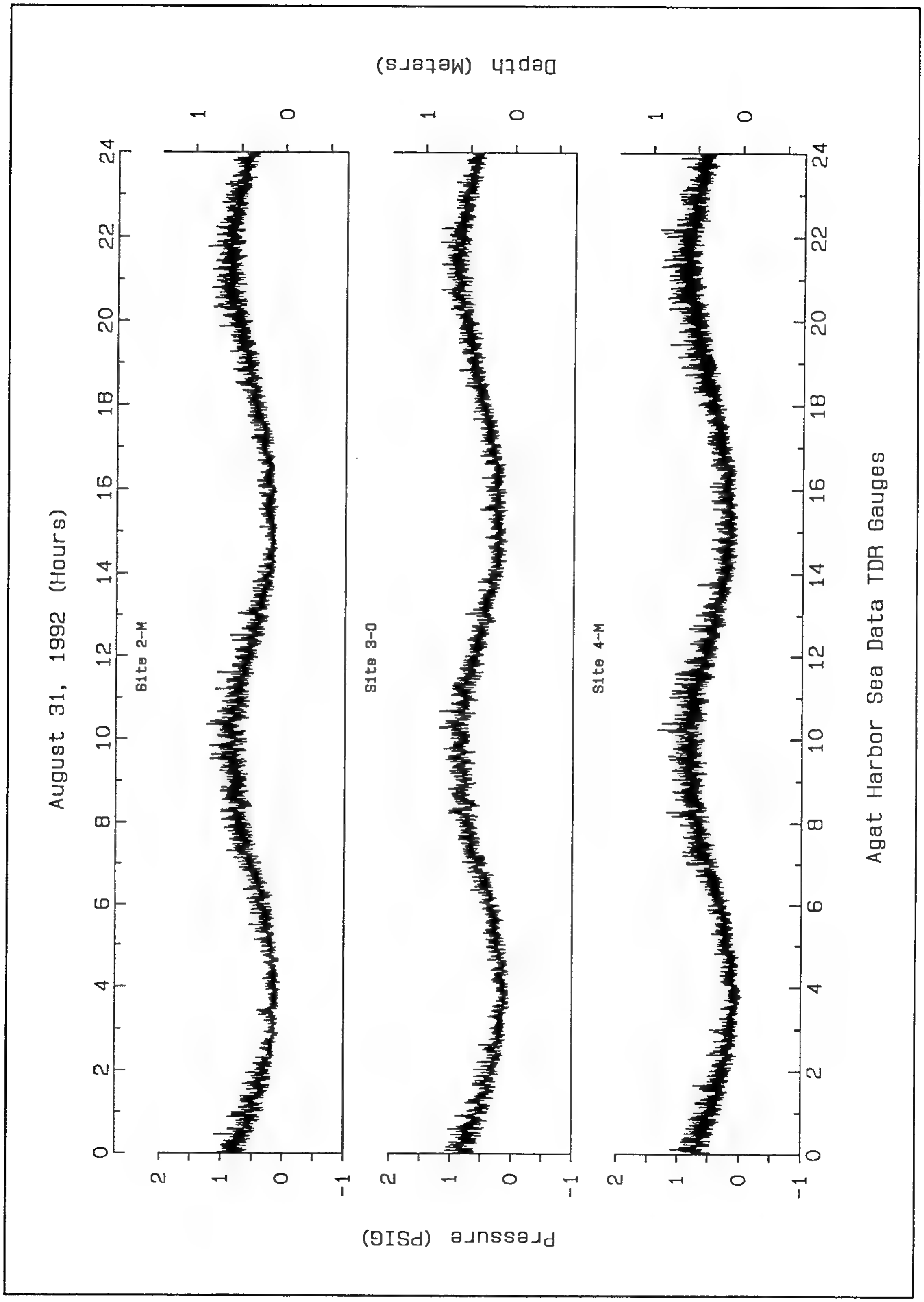
Attachment A

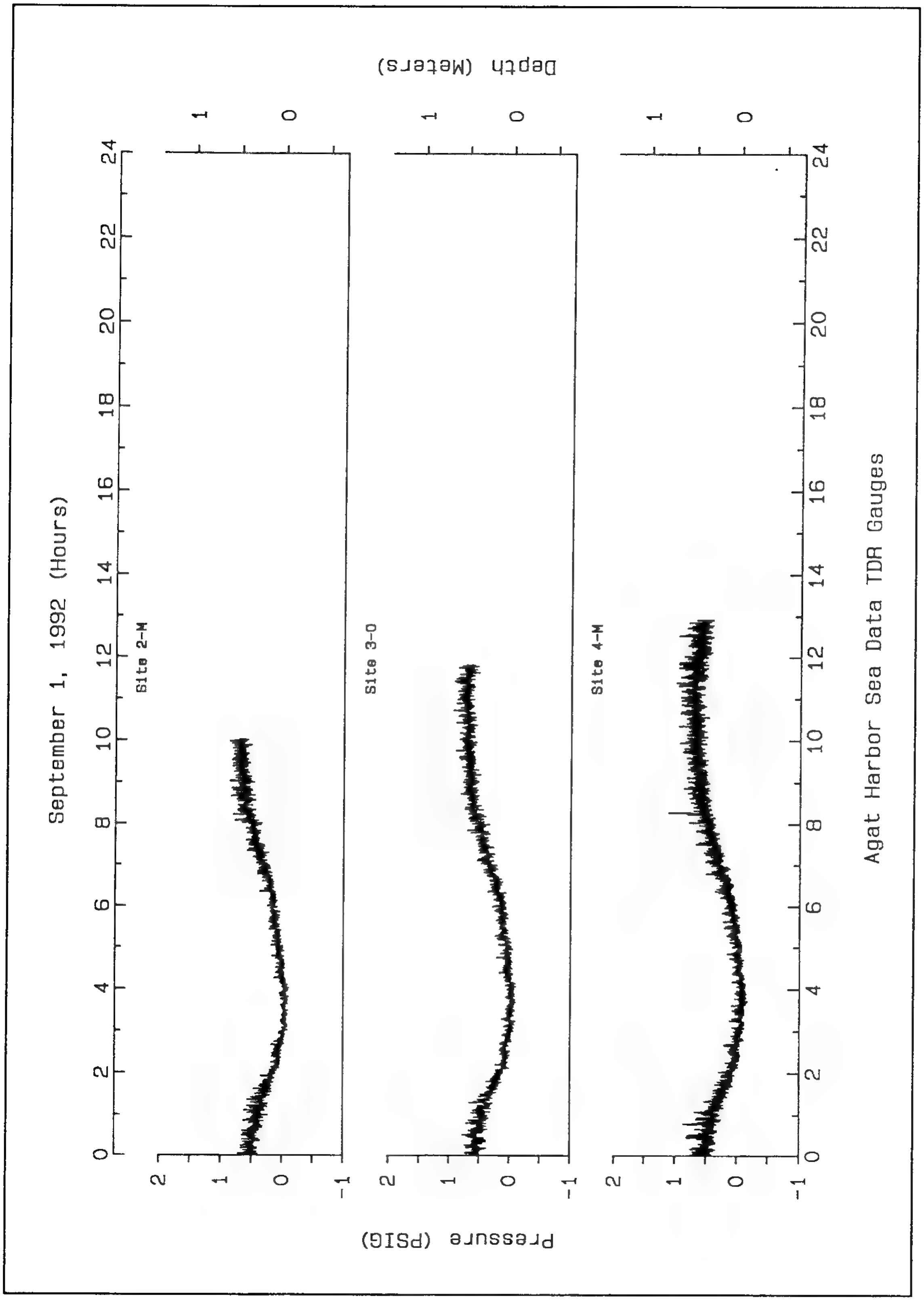

Agat Harbor Sea Data TDR Gauges
August 27, 1992 (Hours)
Site 2-M
Site 3-O
Site 4-M
Pressure (PSIG)
Depth (Meters)


Agat Harbor Sea Data TDR Gauges
August 28, 1992 (Hours)
Site 2-M
Site 3-O
Site 4-M
Pressure (PSIG)
Depth (Meters)


Agat Harbor Sea Data TDR Gauges
August 29, 1992 (Hours)
Site 2-M
Site 3-O
Site 4-M
Pressure (PSIG)
Depth (Meters)


August 30, 1992 (Hours)
Agat Harbor Sea Data TDR Gauges
Pressure (PSIG)
Depth (Meters)
Site 2-M
Site 3-O
Site 4-M


August 31, 1992 (Hours)
Site 2-M
Site 3-O
Site 4-M
Pressure (PSIG)
Depth (Meters)
Agat Harbor Sea Data TDR Gauges



Agat Harbor Sea Data TDR Gauges
September 1, 1992 (Hours)
Pressure (PSIG)
Depth (Meters)
Site 2-M
Site 3-O
Site 4-M

Attachment B

```
Agat Harbor, Guam Sea Data TDR-3 Guage Data
Station:  2-M
Instrument S/N:  414
Sensor Range:  30 PSIG
Sampling Interval:  10 seconds
Start Time:  08/27/92 (240) 14:15:00
End Time:    09/01/92 (245) 10:01:40
Number of Data Points:  41,681
Calibration Factors:
     Calibrated:  April 11, 1992
     Calculated Pressure (PSIG) = (M - B) / S
         where M = Fraction of Full Scale (.XXXX) as measured by the Instrument
               B = 0.077992976
          and, S = 0.030459423
Data Format:  Sequential ASCII data files
              (1x,2i,1x,3i,1x,2i,1x,2i,1x,2x,1x,f5.4,1x,f5.2,1x,f5.2)
     Each Line Contains:
          Year
          Julian Day
          Hour
          Minute
          Second
          TDR Reading (Fraction of Full Scale)
          Pressure (PSIG)
          Depth (Meters)

Comments:



 92 240 14 15  0 0.0531  -0.82  -0.56
 92 240 14 15 10 0.0528  -0.83  -0.57
 92 240 14 15 20 0.0528  -0.83  -0.57
 92 240 14 15 30 0.0531  -0.82  -0.56
 92 240 14 15 40 0.0533  -0.81  -0.56
 92 240 14 15 50 0.0533  -0.81  -0.56
 92 240 14 16  0 0.0533  -0.81  -0.56
 92 240 14 16 10 0.0533  -0.81  -0.56
 92 240 14 16 20 0.0536  -0.80  -0.55
 92 240 14 16 30 0.0538  -0.79  -0.54
 92 240 14 16 40 0.0538  -0.79  -0.54
 92 240 14 16 50 0.0538  -0.79  -0.54
 92 240 14 17  0 0.0538  -0.79  -0.54
 92 240 14 17 10 0.0538  -0.79  -0.54
 92 240 14 17 20 0.0538  -0.79  -0.54
 92 240 14 17 30 0.0541  -0.78  -0.54
 92 240 14 17 40 0.0541  -0.78  -0.54
 92 240 14 17 50 0.0543  -0.78  -0.53
 92 240 14 18  0 0.0543  -0.78  -0.53
 92 240 14 18 10 0.0543  -0.78  -0.53
 92 240 14 18 20 0.0543  -0.78  -0.53
 92 240 14 18 30 0.0543  -0.78  -0.53
 92 240 14 18 40 0.0543  -0.78  -0.53
 92 240 14 18 50 0.0543  -0.78  -0.53
 92 240 14 19  0 0.0543  -0.78  -0.53
 92 240 14 19 10 0.0545  -0.77  -0.53
 92 240 14 19 20 0.0548  -0.76  -0.52
 92 240 14 19 30 0.0548  -0.76  -0.52
 92 240 14 19 40 0.0548  -0.76  -0.52
 92 240 14 19 50 0.0548  -0.76  -0.52
 92 240 14 20  0 0.0548  -0.76  -0.52
 92 240 14 20 10 0.0548  -0.76  -0.52
 92 240 14 20 20 0.0548  -0.76  -0.52
 92 240 14 20 30 0.0548  -0.76  -0.52
 92 240 14 20 40 0.0548  -0.76  -0.52
 92 240 14 20 50 0.0548  -0.76  -0.52
 92 240 14 21  0 0.0548  -0.76  -0.52
 92 240 14 21 10 0.0550  -0.75  -0.52
 92 240 14 21 20 0.0550  -0.75  -0.52
 92 240 14 21 30 0.0550  -0.75  -0.52
 92 240 14 21 40 0.0550  -0.75  -0.52
 92 240 14 21 50 0.0553  -0.75  -0.51
 92 240 14 22  0 0.0553  -0.75  -0.51
 92 240 14 22 10 0.0553  -0.75  -0.51
 92 240 14 22 20 0.0553  -0.75  -0.51
 92 240 14 22 30 0.0553  -0.75  -0.51
 92 240 14 22 40 0.0553  -0.75  -0.51
 92 240 14 22 50 0.0553  -0.75  -0.51
 92 240 14 23  0 0.0553  -0.75  -0.51
```

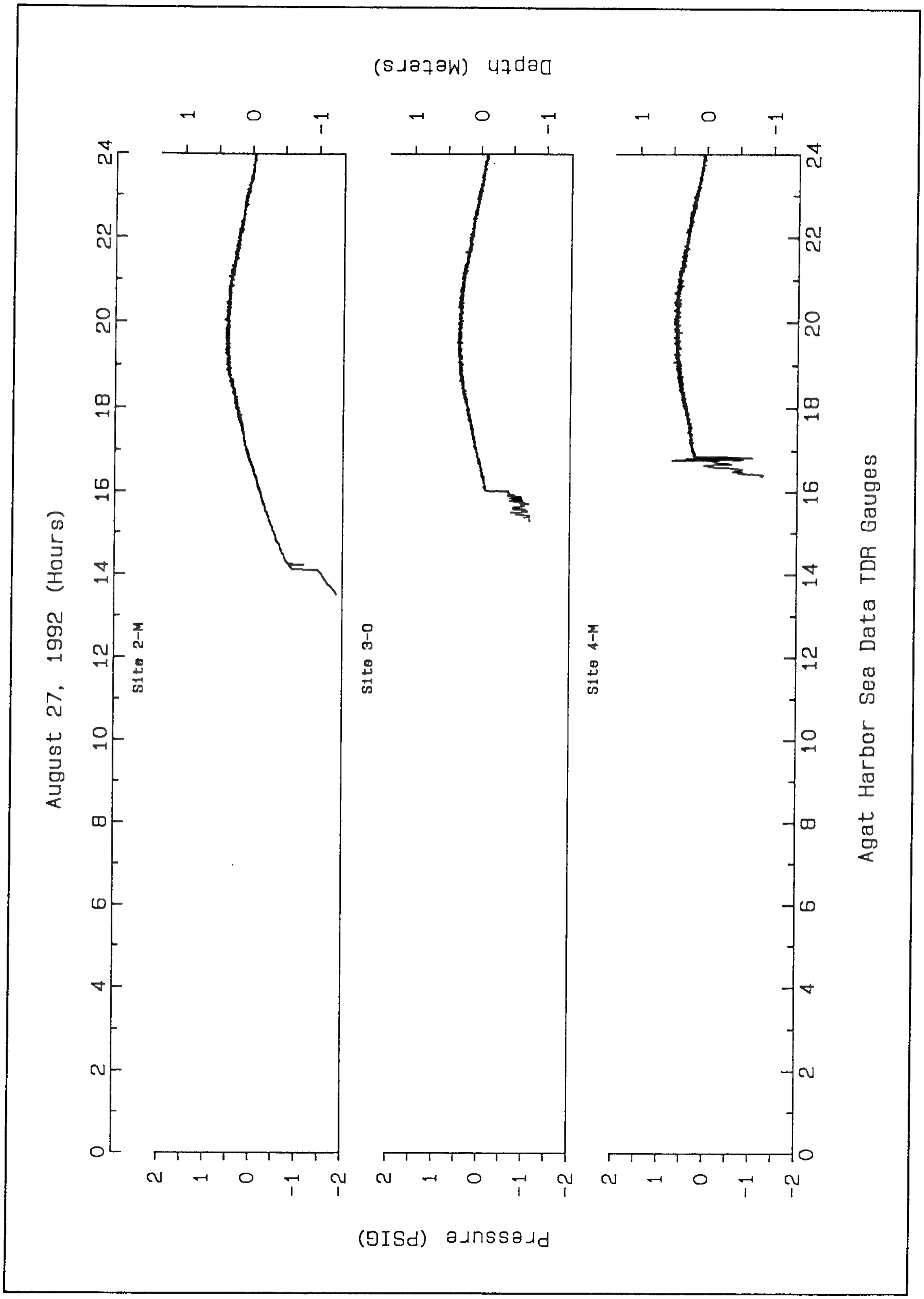
```
Agat Harbor, Guam Sea Data TDR-3 Guage Data
Station:  3-0
Instrument S/N:  155
Sensor Range:  30 PSIG
Sampling Interval:  10 seconds
Start Time:  08/27/92 (240) 16:09:10
End Time:    09/01/92 (245) 11:48:50
Number of Data Points:  41,639
Calibration Factors:
      Calibrated:  April 16, 1990
      Calculated Pressure (PSIG) = (M - B) / S
           where M = Fraction of Full Scale (.XXXX) as measured by the Instrument
                   B = 0.077228427
            and, S = 0.030172294
Data Format:  Sequential ASCII data files
                (1x,2i,1x,3i,1x,2i,1x,2i,1x,2x,1x,f5.4,1x,f5.2,1x,f5.2)
      Each Line Contains:
            Year
            Julian Day
            Hour
            Minute
            Second
            TDR Reading (Fraction of Full Scale)
            Pressure (PSIG)
            Depth (Meters)

Comments:
```

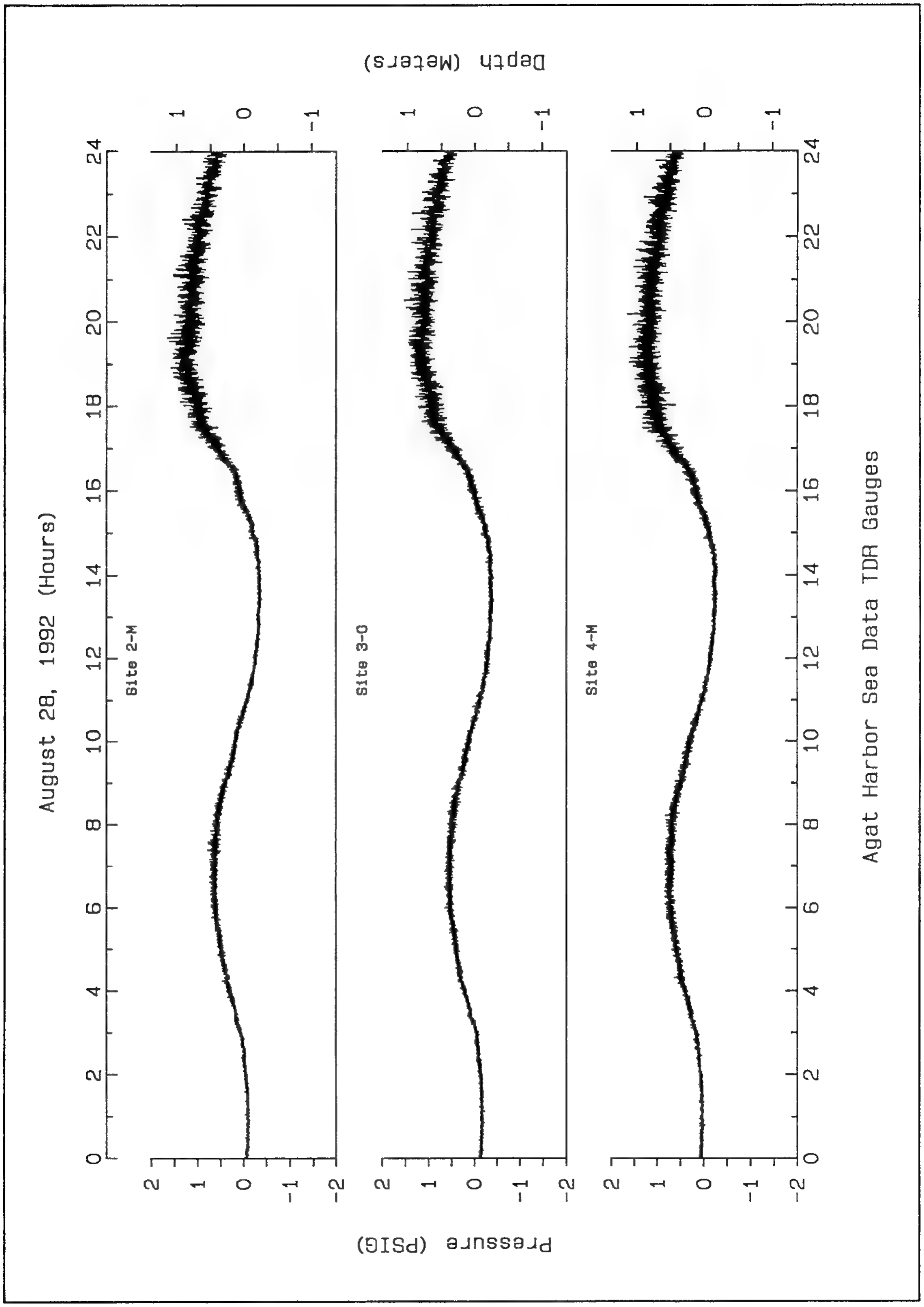
92	240	16	9	10	0.0736	-0.12	-0.08
92	240	16	9	20	0.0736	-0.12	-0.08
92	240	16	9	30	0.0736	-0.12	-0.08
92	240	16	9	40	0.0736	-0.12	-0.08
92	240	16	9	50	0.0736	-0.12	-0.08
92	240	16	10	0	0.0738	-0.11	-0.08
92	240	16	10	10	0.0741	-0.10	-0.07
92	240	16	10	20	0.0741	-0.10	-0.07
92	240	16	10	30	0.0741	-0.10	-0.07
92	240	16	10	40	0.0743	-0.10	-0.07
92	240	16	10	50	0.0738	-0.11	-0.08
92	240	16	11	0	0.0736	-0.12	-0.08
92	240	16	11	10	0.0741	-0.10	-0.07
92	240	16	11	20	0.0738	-0.11	-0.08
92	240	16	11	30	0.0738	-0.11	-0.08
92	240	16	11	40	0.0738	-0.11	-0.08
92	240	16	11	50	0.0741	-0.10	-0.07
92	240	16	12	0	0.0743	-0.10	-0.07
92	240	16	12	10	0.0741	-0.10	-0.07
92	240	16	12	20	0.0741	-0.10	-0.07
92	240	16	12	30	0.0738	-0.11	-0.08
92	240	16	12	40	0.0738	-0.11	-0.08
92	240	16	12	50	0.0738	-0.11	-0.08
92	240	16	13	0	0.0738	-0.11	-0.08
92	240	16	13	10	0.0743	-0.10	-0.07
92	240	16	13	20	0.0745	-0.09	-0.06
92	240	16	13	30	0.0741	-0.10	-0.07
92	240	16	13	40	0.0741	-0.10	-0.07
92	240	16	13	50	0.0743	-0.10	-0.07
92	240	16	14	0	0.0738	-0.11	-0.08
92	240	16	14	10	0.0741	-0.10	-0.07
92	240	16	14	20	0.0741	-0.10	-0.07
92	240	16	14	30	0.0743	-0.10	-0.07
92	240	16	14	40	0.0745	-0.09	-0.06
92	240	16	14	50	0.0741	-0.10	-0.07
92	240	16	15	0	0.0743	-0.10	-0.07
92	240	16	15	10	0.0743	-0.10	-0.07
92	240	16	15	20	0.0741	-0.10	-0.07
92	240	16	15	30	0.0743	-0.10	-0.07
92	240	16	15	40	0.0743	-0.10	-0.07
92	240	16	15	50	0.0743	-0.10	-0.07
92	240	16	16	0	0.0741	-0.10	-0.07
92	240	16	16	10	0.0743	-0.10	-0.07
92	240	16	16	20	0.0743	-0.10	-0.07
92	240	16	16	30	0.0741	-0.10	-0.07
92	240	16	16	40	0.0745	-0.09	-0.06
92	240	16	16	50	0.0745	-0.09	-0.06
92	240	16	17	0	0.0743	-0.10	-0.07
92	240	16	17	10	0.0745	-0.09	-0.06

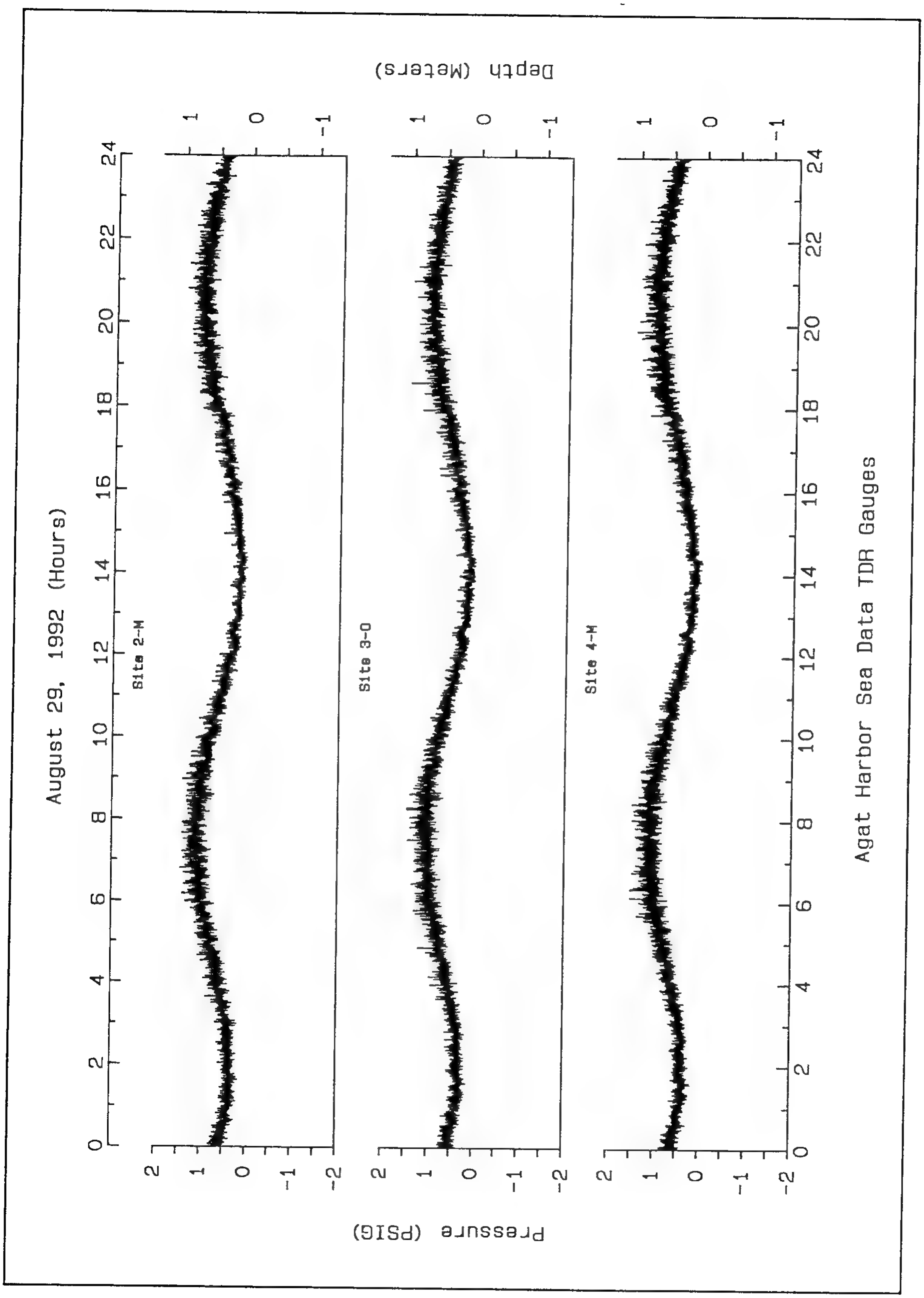
Agat Harbor, Guam Sea Data TDR-3 Guage Data
Station: 4-M
Instrument S/N: 069
Sensor Range: 30 PSIG
Sampling Interval: 10 seconds
Start Time: 08/27/92 (240) 16:56:30
End Time: 09/01/92 (245) 12:54:50
Number of Data Points: 41,751
Calibration Factors:
    Calibrated: April 16, 1992
    Calculated Pressure (PSIG) = (M - B) / S
        where M = Fraction of Full Scale (.XXXX) as measured by the Instrument
              B = 0.070407093
        and, S = 0.030402575
Data Format: Sequential ASCII data files
              (1x,2i,1x,3i,1x,2i,1x,2i,1x,2x,1x,f5.4,1x,f5.2,1x,f5.2)
    Each Line Contains:
        Year
        Julian Day
        Hour
        Minute
        Second
        TDR Reading (Fraction of Full Scale)
        Pressure (PSIG)
        Depth (Meters)

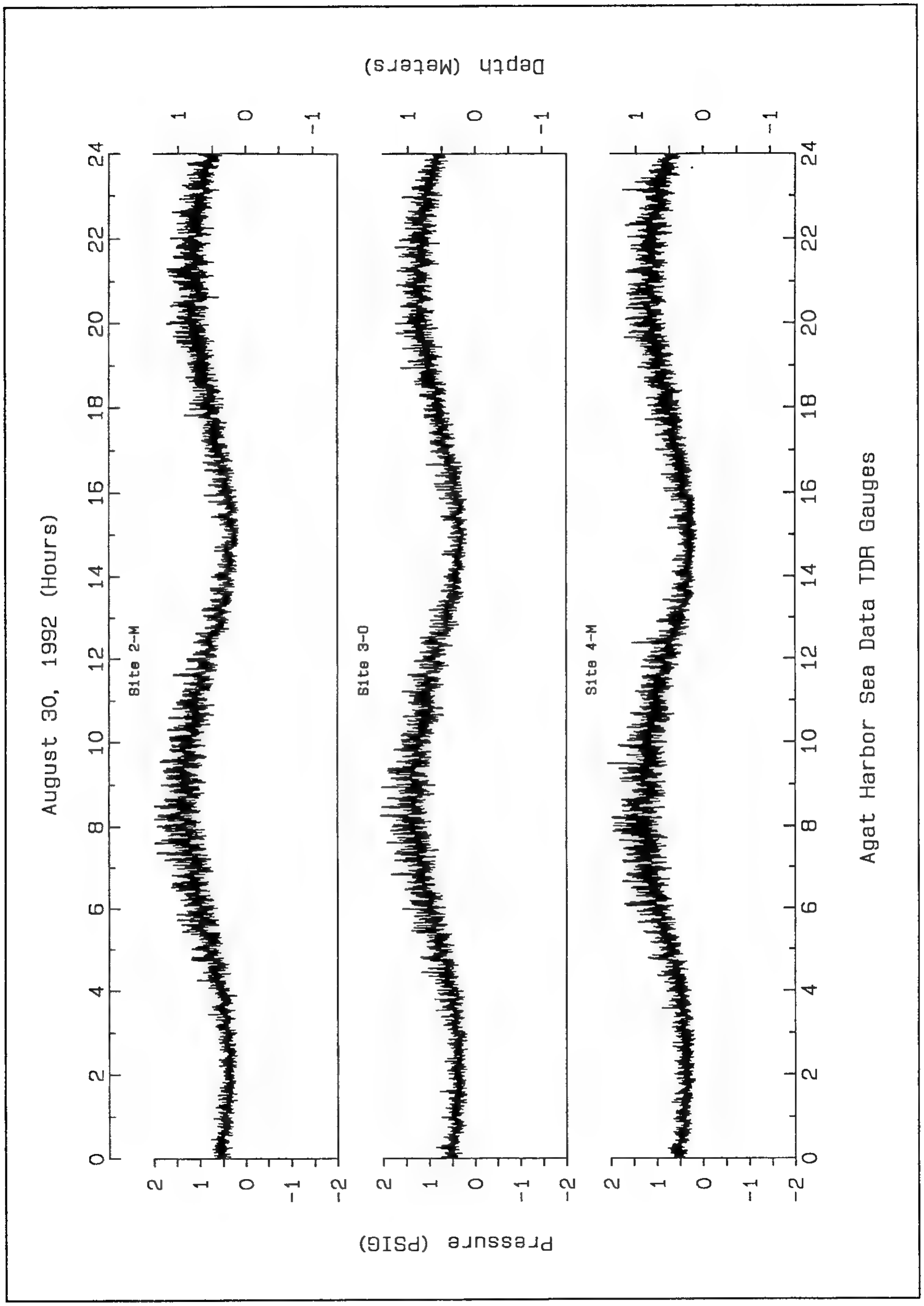
Comments: TDR and anchor moved approximately 100 feet to North during storm. Some data may reflect movement of TDR. There is a 2 minute time difference between the time the instrument recorded the first data point and the log sheet. The time associated with the clock reset was used for the conversion to engineering units.

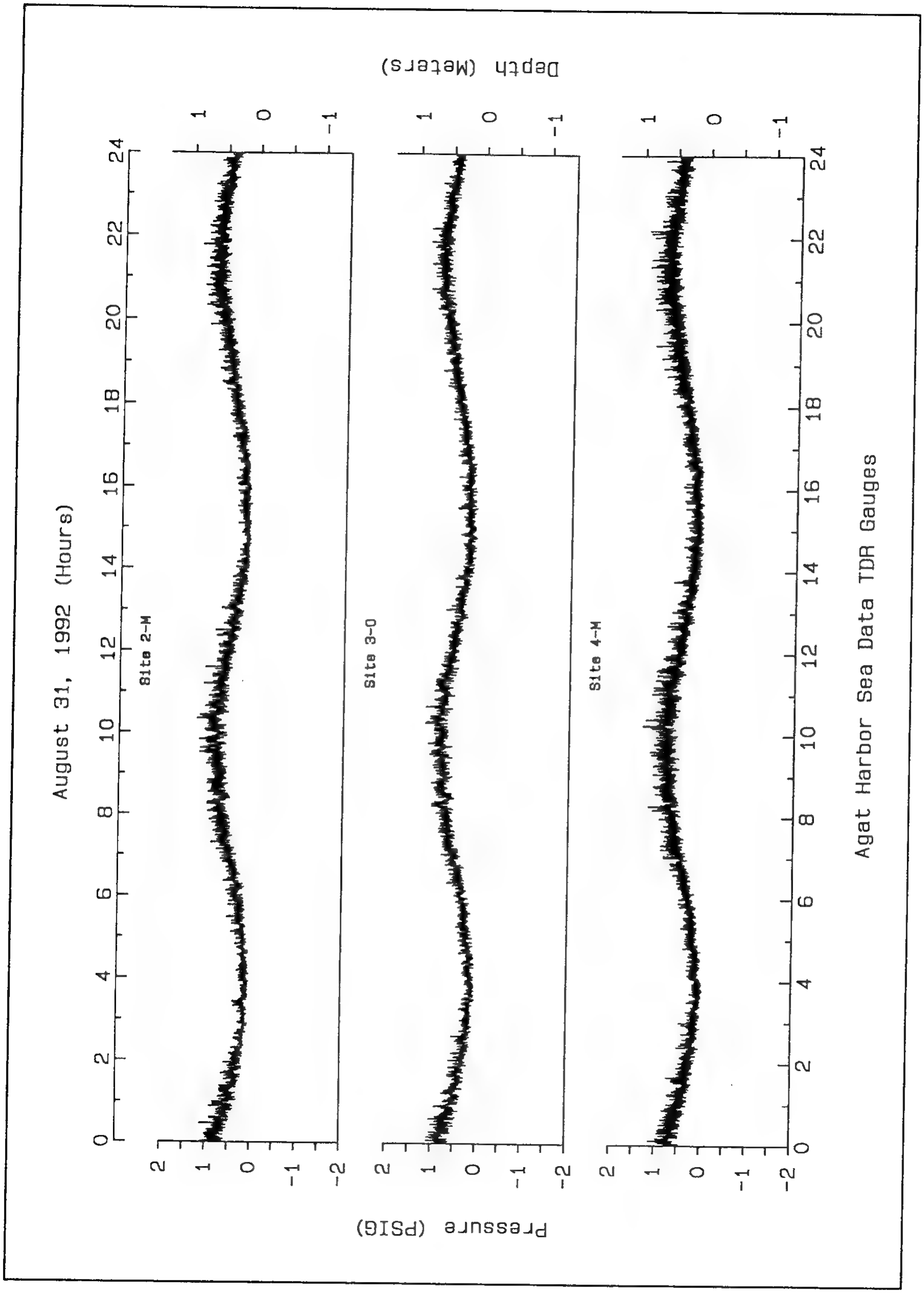
92	240	16	56	30	0.0782	0.26	0.18
92	240	16	56	40	0.0782	0.26	0.18
92	240	16	56	50	0.0782	0.26	0.18
92	240	16	57	0	0.0782	0.26	0.18
92	240	16	57	10	0.0784	0.26	0.18
92	240	16	57	20	0.0782	0.26	0.18
92	240	16	57	30	0.0780	0.25	0.17
92	240	16	57	40	0.0774	0.23	0.16
92	240	16	57	50	0.0789	0.28	0.19
92	240	16	58	0	0.0786	0.27	0.18
92	240	16	58	10	0.0784	0.26	0.18
92	240	16	58	20	0.0784	0.26	0.18
92	240	16	58	30	0.0782	0.26	0.18
92	240	16	58	40	0.0786	0.27	0.18
92	240	16	58	50	0.0789	0.28	0.19
92	240	16	59	0	0.0782	0.26	0.18
92	240	16	59	10	0.0780	0.25	0.17
92	240	16	59	20	0.0784	0.26	0.18
92	240	16	59	30	0.0777	0.24	0.16
92	240	16	59	40	0.0789	0.28	0.19
92	240	16	59	50	0.0794	0.30	0.20
92	240	17	0	0	0.0784	0.26	0.18
92	240	17	0	10	0.0782	0.26	0.18
92	240	17	0	20	0.0786	0.27	0.18
92	240	17	0	30	0.0789	0.28	0.19
92	240	17	0	40	0.0794	0.30	0.20
92	240	17	0	50	0.0789	0.28	0.19
92	240	17	1	0	0.0784	0.26	0.18
92	240	17	1	10	0.0786	0.27	0.18
92	240	17	1	20	0.0789	0.28	0.19
92	240	17	1	30	0.0789	0.28	0.19
92	240	17	1	40	0.0782	0.26	0.18
92	240	17	1	50	0.0786	0.27	0.18
92	240	17	2	0	0.0784	0.26	0.18
92	240	17	2	10	0.0782	0.26	0.18
92	240	17	2	20	0.0794	0.30	0.20
92	240	17	2	30	0.0794	0.30	0.20
92	240	17	2	40	0.0786	0.27	0.18
92	240	17	2	50	0.0789	0.28	0.19
92	240	17	3	0	0.0792	0.29	0.20
92	240	17	3	10	0.0789	0.28	0.19
92	240	17	3	20	0.0796	0.30	0.21
92	240	17	3	30	0.0796	0.30	0.21
92	240	17	3	40	0.0784	0.26	0.18
92	240	17	3	50	0.0792	0.29	0.20
92	240	17	4	0	0.0786	0.27	0.18
92	240	17	4	10	0.0786	0.27	0.18
92	240	17	4	20	0.0789	0.28	0.19
92	240	17	4	30	0.0789	0.28	0.19

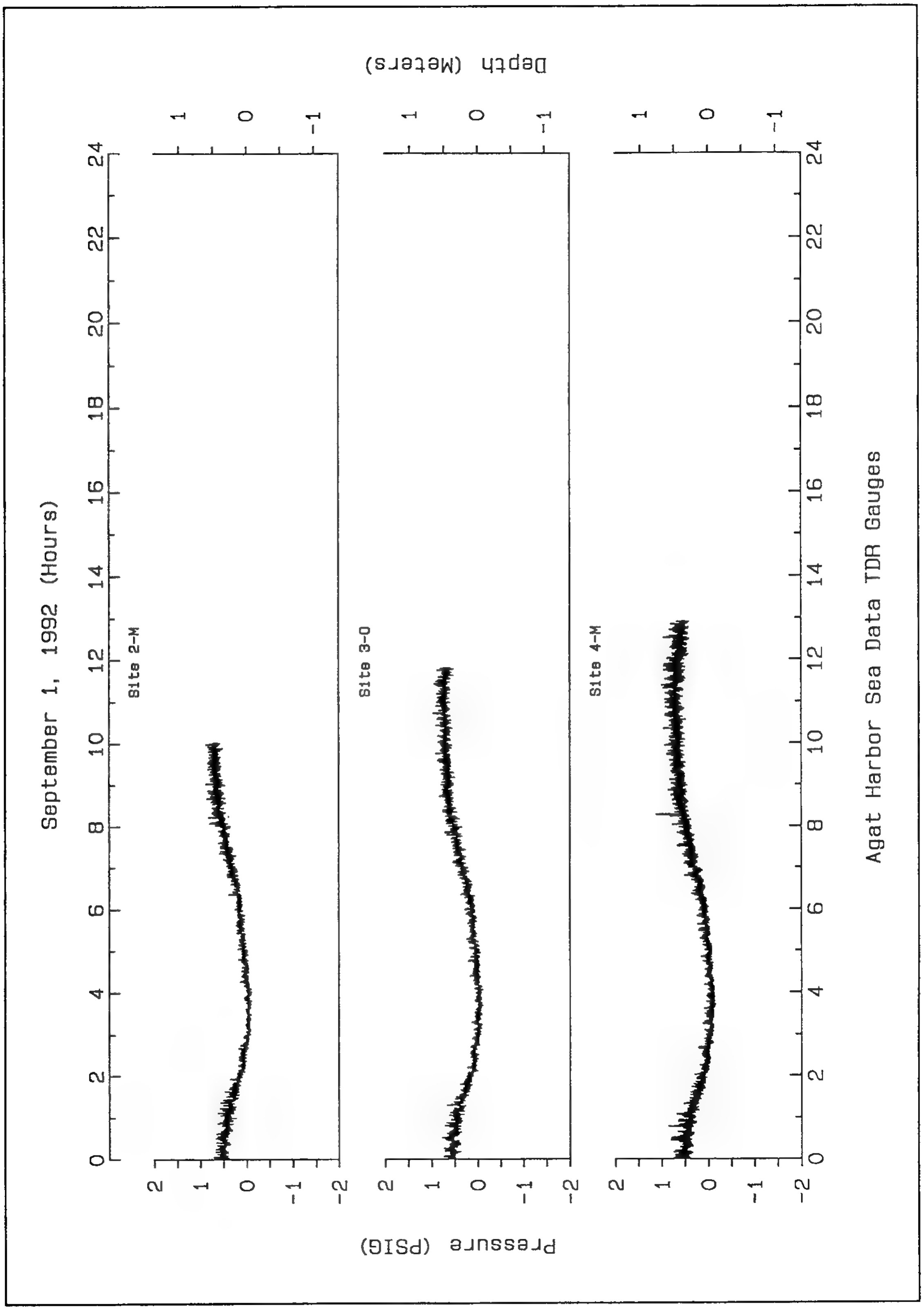

August 27, 1992 (Hours)
Site 2-M
Site 3-O
Site 4-M
Depth (Meters)
Pressure (PSIG)
Agat Harbor Sea Data TDR Gauges


Agat Harbor Sea Data TDR Gauges
August 28, 1992 (Hours)
Site 2-M
Site 3-O
Site 4-M
Pressure (PSIG)
Depth (Meters)

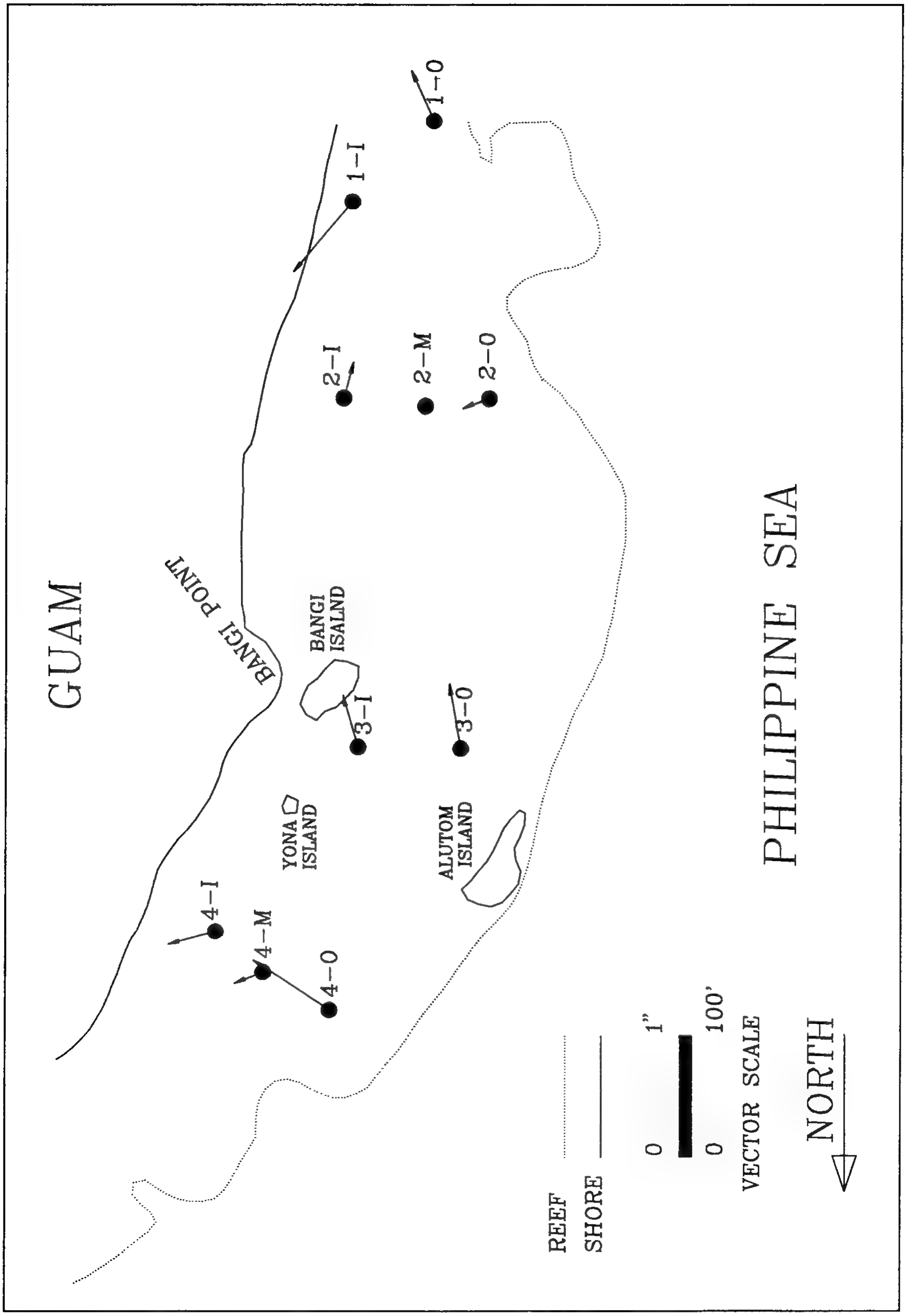

August 29, 1992 (Hours)
Depth (Meters)
Pressure (PSIG)
Site 2-M
Site 3-O
Site 4-M
Agat Harbor Sea Data TDR Gauges


Agat Harbor Sea Data TDR Gauges
August 30, 1992 (Hours)
Pressure (PSIG)
Depth (Meters)
Site 2-M
Site 3-O
Site 4-M


August 31, 1992 (Hours)
Agat Harbor Sea Data TDR Gauges
Site 2-M
Site 3-O
Site 4-M
Depth (Meters)
Pressure (PSIG)


Agat Harbor Sea Data TDR Gauges
September 1, 1992 (Hours)
Site 2-M
Site 3-O
Site 4-M
Pressure (PSIG)
Depth (Meters)

Attachment C


GUAM
BANGI POINT
BANGI ISALND
YONA ISLAND
ALUTOM ISLAND
PHILIPPINE SEA
1-I
1-0
2-I
2-M
2-0
3-I
3-0
4-I
4-M
4-0
REEF
SHORE
0 1"
0 100'
VECTOR SCALE
NORTH

Attachment D

Agat Harbor Current Study
Eulerian Current Measurements
Dry Run Deployment

August 7, 1992
File: 4400-66

Date	Time	Station Number	Current Speed (cm/sec)	Wind Speed (mph)	Wind Direction	Minimum Water Depth (Ft.)	Maximum Water Depth (Ft.)
08-07-92	1158	2-Inner	0.01	< 5	130	1.08	1.17
08-07-92	1220	2-Middle	0.52	< 5	120	2.25	2.33
08-07-92	1235	2-Outter	0.25	< 5	130	2.58	2.75

Agat Harbor Current Study
Eulerian Current Measurements
First Deployment

August 27, 1992
File: 4400-66

Date	Time	Station Number	Current Speed (cm/sec)	Wind Speed (mph)	Wind Direction	Minimum Water Depth (Ft.)	Maximum Water Depth (Ft.)
08-27-92	1455	1-Inner	8.20	5-10	030	1.33	1.42
08-27-92	1443	1-Outter	0.03	5-15	015	2.25	2.42
08-27-92	1345	2-Inner	0.06	5-15	030	1.04	1.13
08-27-92	1405	2-Middle	0.06	5-15	020	1.17	1.29
08-27-92	1420	2-Outter	0.16	5-15	015	1.50	1.58
08-27-92	1530	3-Inner	0.03	15-20	355	1.33	1.67
08-27-92	1555	3-Outter	0.04	15-25	355	1.75	1.92
08-27-92	1633	4-Inner	0.27	10-15	355	3.58	4.00
08-27-92	1655	4-Middle	1.57	15	355	3.50	4.08
08-27-92	1707	4-Outter	0.52	15-20	355	4.33	5.08

EVANS-HAMILTON, INC.
VICKSBURG OFFICE
3202 WISCONSIN AVE.
VICKSBURG, MISSISSIPPI 39180

TEL.: (601) 638-0646
FAX: (601) 634-0631

TO: Dave King

FROM: Jeanne Simmons

DATE: December 1, 1992

SUBJECT: Delivery Order #33 - Guam Current Study - 2nd Deployment

FILE: 4400.66

The following information about the second storm event was supplied by PBEC:

Typhoon Brian passed over Guam on October 21, 1992. The force of the storm was not nearly as much as predicted. In fact, the ocean on the western side of the island remained quite calm through the approach of the storm and even after it passed. The ocean swell picked up significantly on Friday, October 23 and stayed up through the weekend. The swell was attributed not only to Typhoon Brian, but also to Typhoon Colleen which was far off (towards the Philippines) but strong. PBEC retrieved the TDRs on October 27th. Because the TDRs were no longer collecting data at the time of retrieval, PBEC did not conduct the other field tests at that time. The TDR sampling interval was set at 10 seconds, so there is a total of approximately 5 days and 15 hours of data available from each TDR.

As mentioned previously, TDR#414 which was located at Station 4-M did not have any data. It appears the battery was bad (and has since been replaced). Similar to the first deployment, Station 4-M was knocked over by the currents. This time the TDR and the anchor were found approximately 50 feet northeast of their original location. PBEC attached the battery from one of the other TDRs to TDR#414, and it operated fine.

COMMENTS RECORDED FOR EACH STATION:

On October 20, 1992, the following comments were recorded at each station:

Station 1-inner & 1-outer - heavy rains, winds variable 10-20 mph, low tide

- Station 2-inner,2-middle & 2-outer - variable winds 5-15 mph, low tide, scattered showers

Station 3-inner & 3-outer - at 3-inner, it was too shallow for any current measurements. Station 3-outer is in a slight depression with coral and seagrass beds around it. PBEC could have taken current measurements; however, the measurements would be significantly influenced by the "channeling" of water around/between the coral and seagrass beds which would be misleading.

Station 4-inner, 4-middle & 4-outer - low tide

On October 23, 1992, the following comments were recorded at each station:

Station 4-inner & 3-inner - these data were collected while the TDRs were deployed. Surf and current conditions were high. Current velocity was strong and variable. Water depth seemed to vary from high and rough to lower and calmer at about 5 minute intervals. Conditions became too rough to continue field data collection.

INDEX OF ATTACHMENTS

Attachment A - TDR Time Series Data from 10/20/92 - 10/25/92

The final data files are on the diskette in the same format as the first deployment. The only editing done to the data was deleting the bad data at the beginning of each record. To calculate depth, the Saunders and Fofonoff's method was used which can be found in the 1983 Unesco technical papers (Algorithms for computation of fundamental properties of seawater). The last two plots in Attachment A show one hour of high tide data at the peak of the storm on October 24 at 1800-1900 hrs, and one hour of low tide data at the peak of the storm on October 25 at 0000-0100 hrs.

Attachment B - Eularian Current Measurements

The table shows Eularian current measurements taken on October 20th and 23rd. The Standard Speed Rotor Constant of 26,873 was used. The table is also included on the disk in ASCII format.

Attachment C - Lagrangian Current Measurements

For the deployment on October 20, 1992, a table was created to display the data, and a map shows the corresponding locations and directions of drogue drift.

Since the first deployment, we have acquired a better map to digitize. So, I have included a new version of the Lagrangian

current measurements for the deployment on August 27, 1992. The table and map are also included in Attachment C.

Attachment D - Dry Run TDR Data and Eularian Current Measurements

The remainder of data collected on August 7, 1992 for the dry run have been included. The dry run was performed on a very calm day. Only one TDR was deployed and field measurements were collected for only one transect. The TDR data was collected for only a few hours, as the TDR was deployed and retrieved on the same day.

Attachment E - Miscellaneous Information

PBEC included some newspaper articles that contain weather and storm information for October 19th, 21st, 22nd and 23rd.

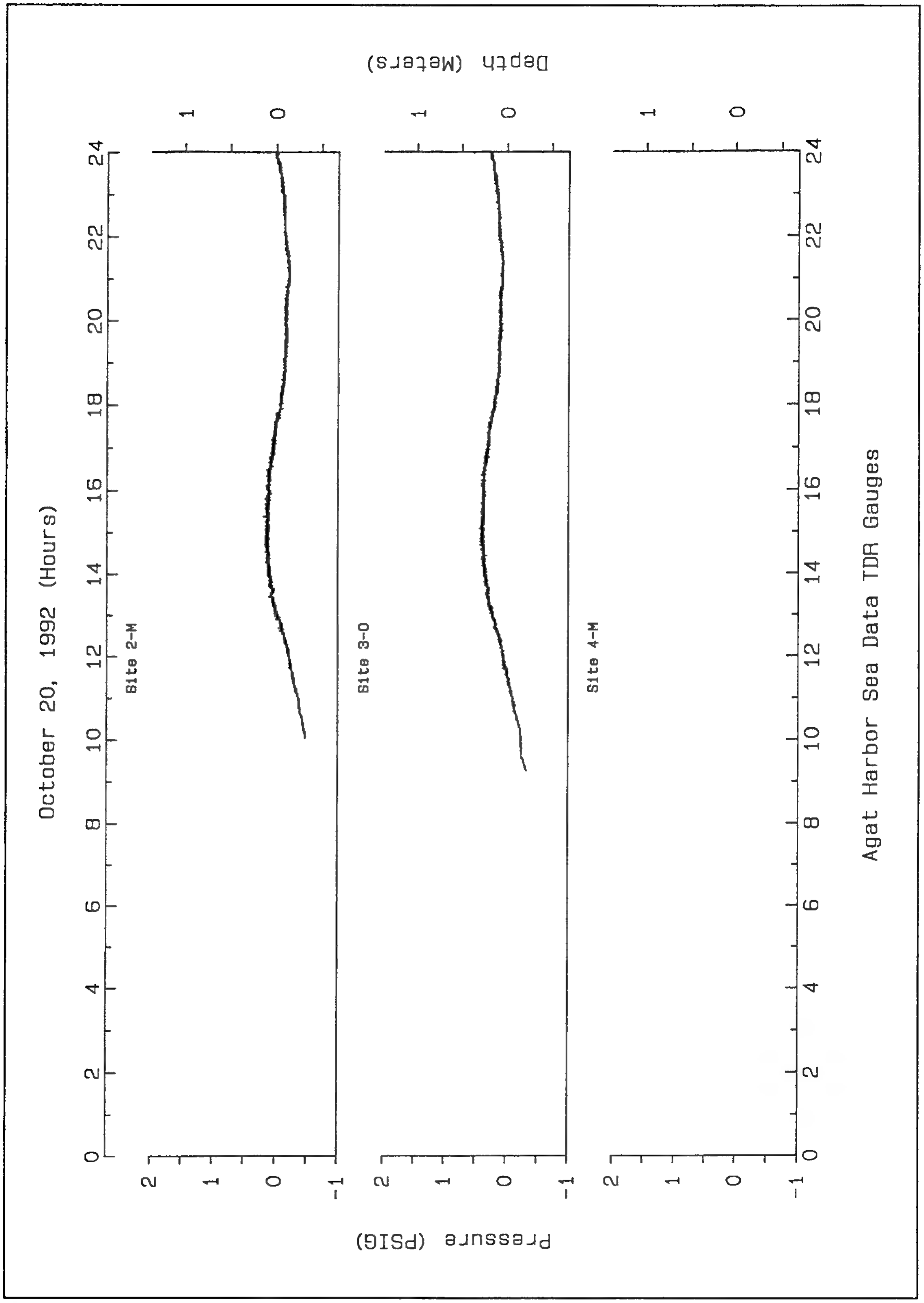
If you have any questions about the enclosed material, please do not hesitate to contact me.

Sincerely,

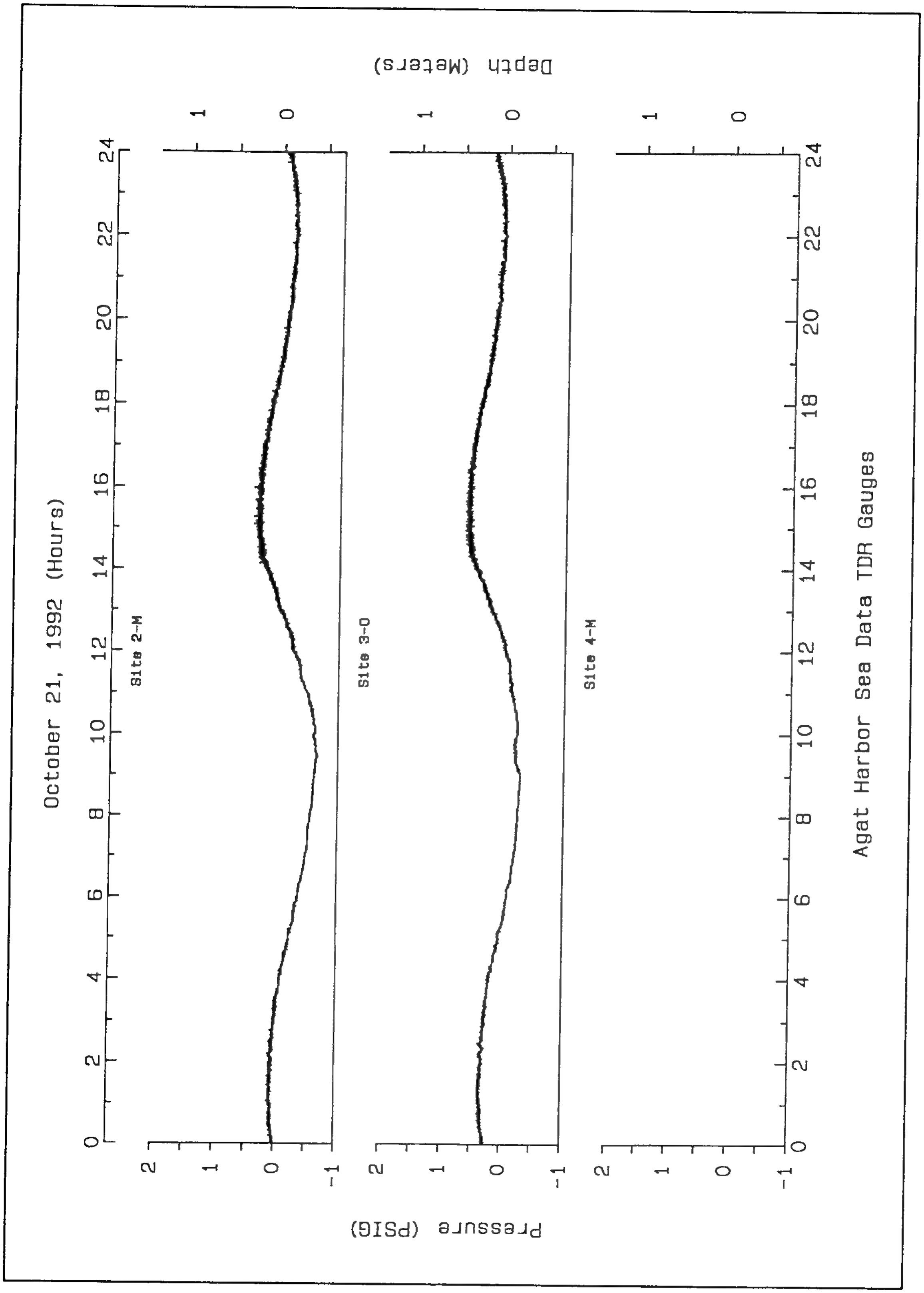
Jeanne Simmons

Jeanne Simmons
Oceanographer

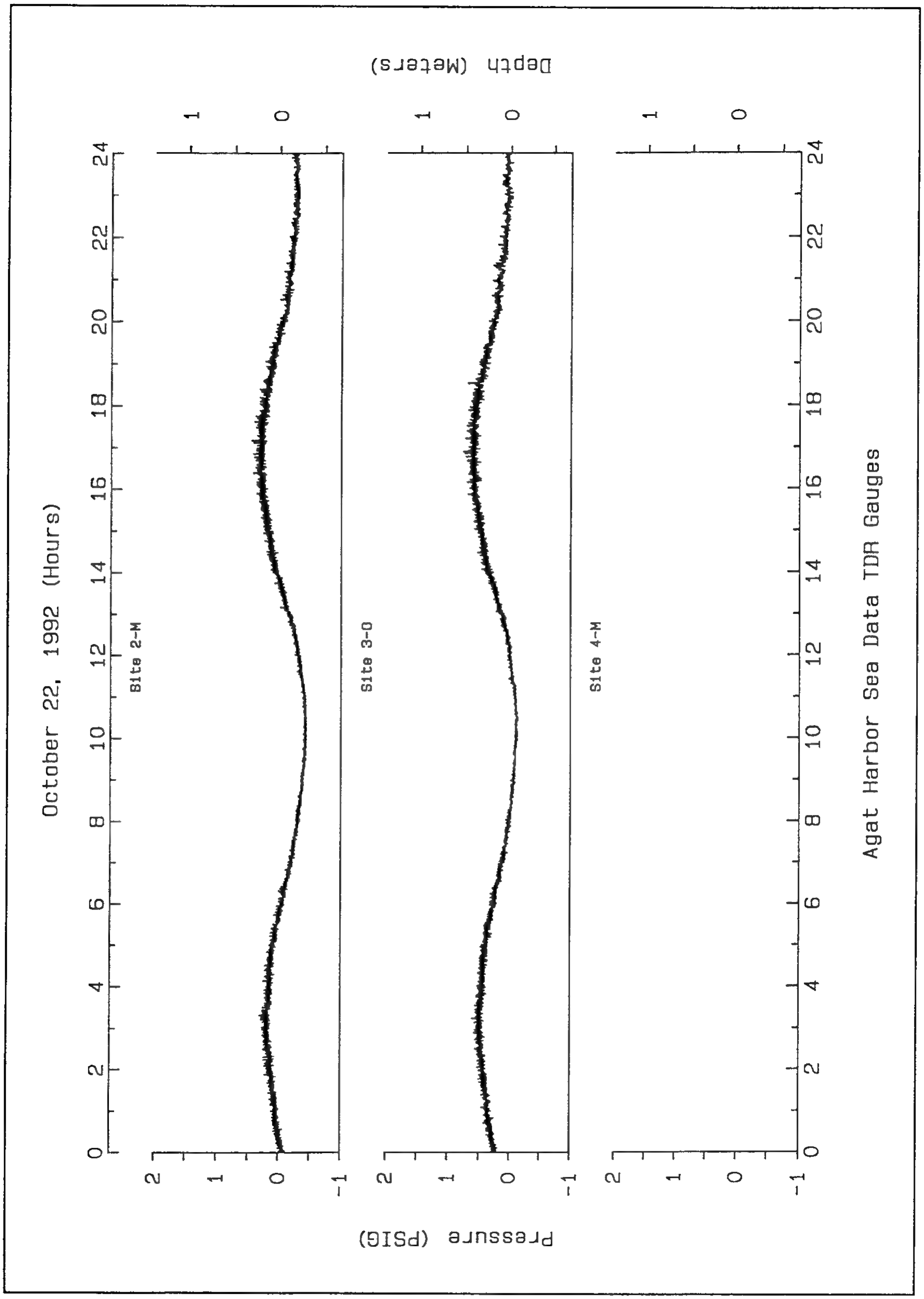
Attachment A

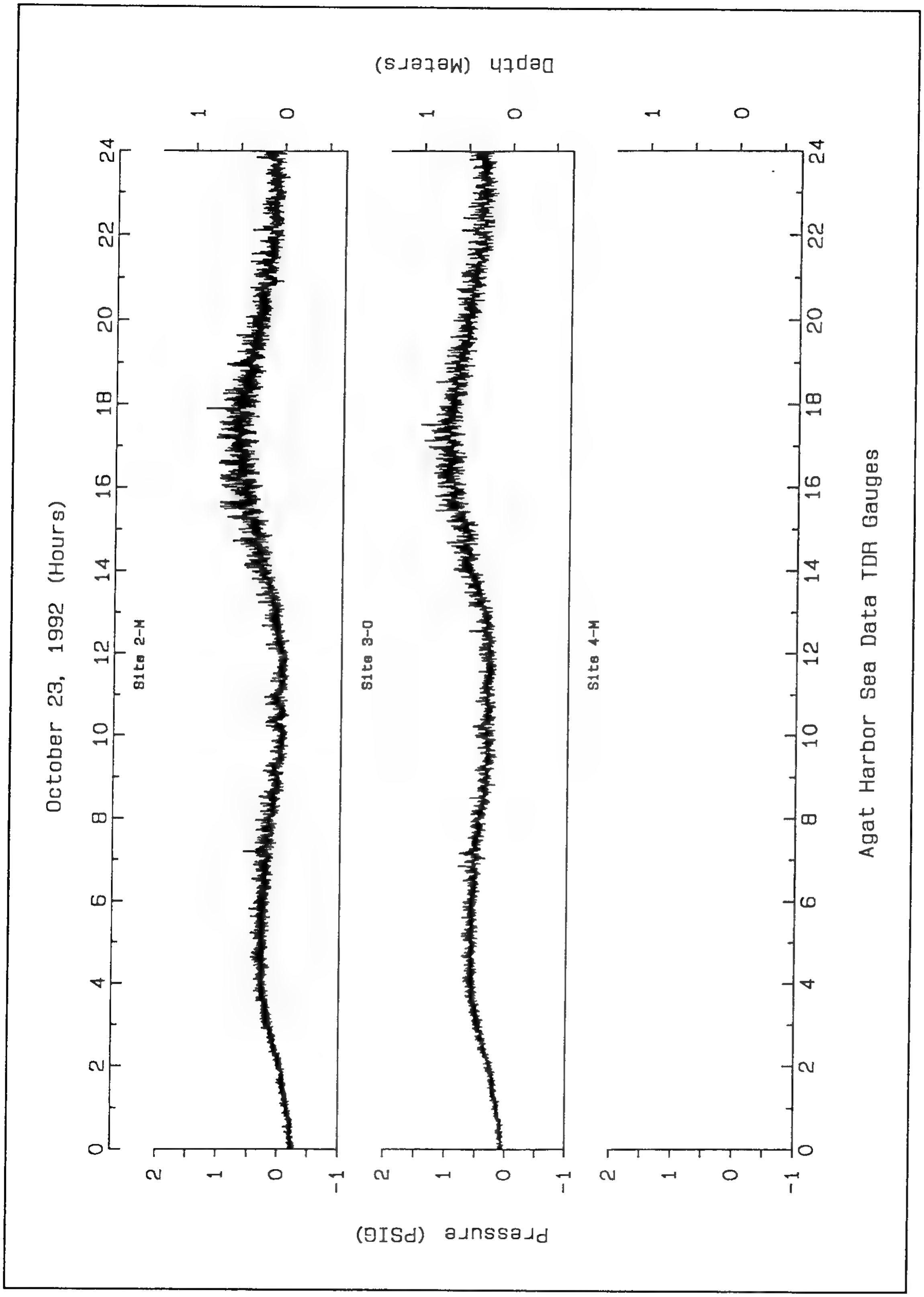


Agat Harbor Sea Data TDR Gauges
October 20, 1992 (Hours)
Site 2-M
Site 3-O
Site 4-M
Depth (Meters)
Pressure (PSIG)

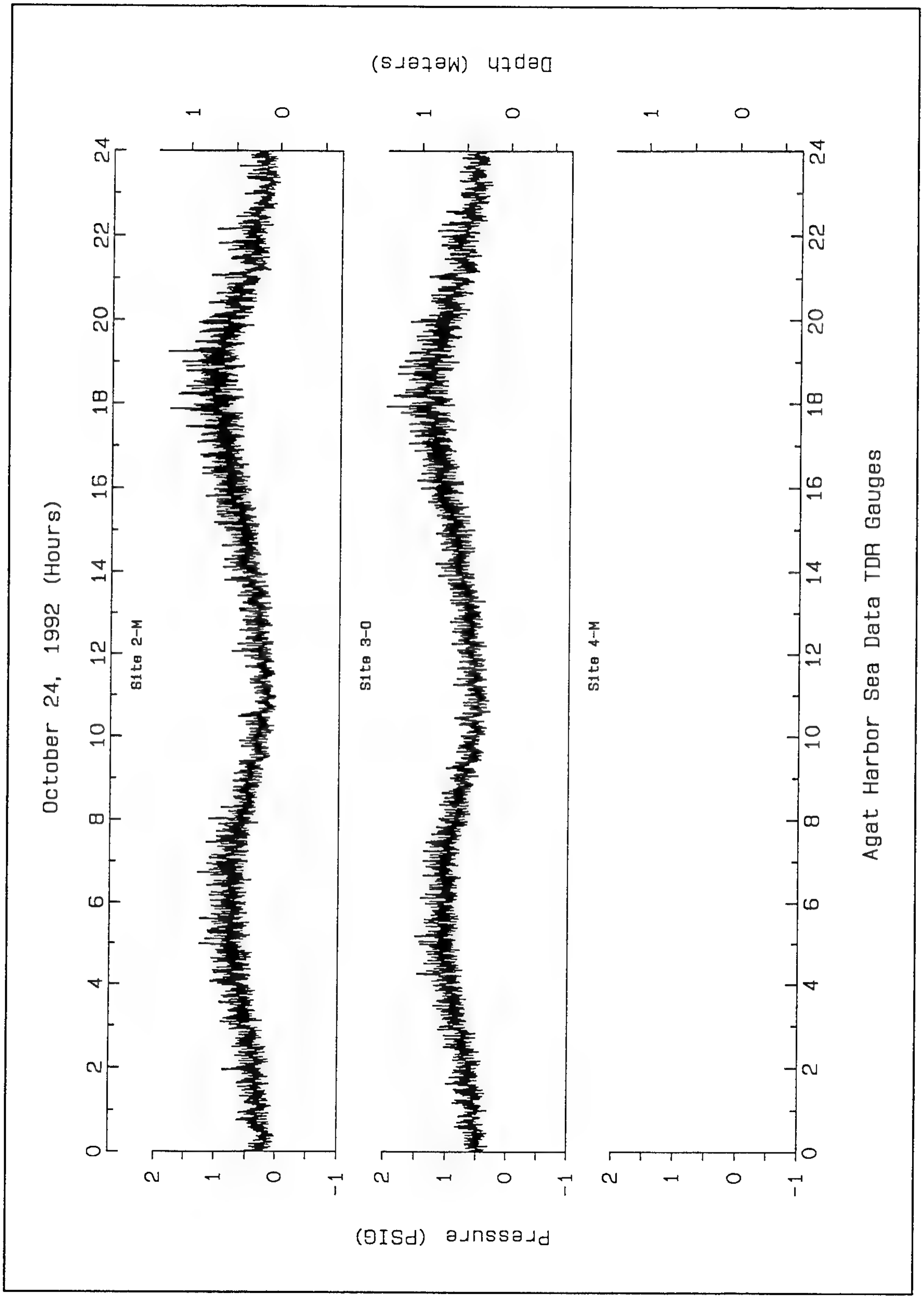


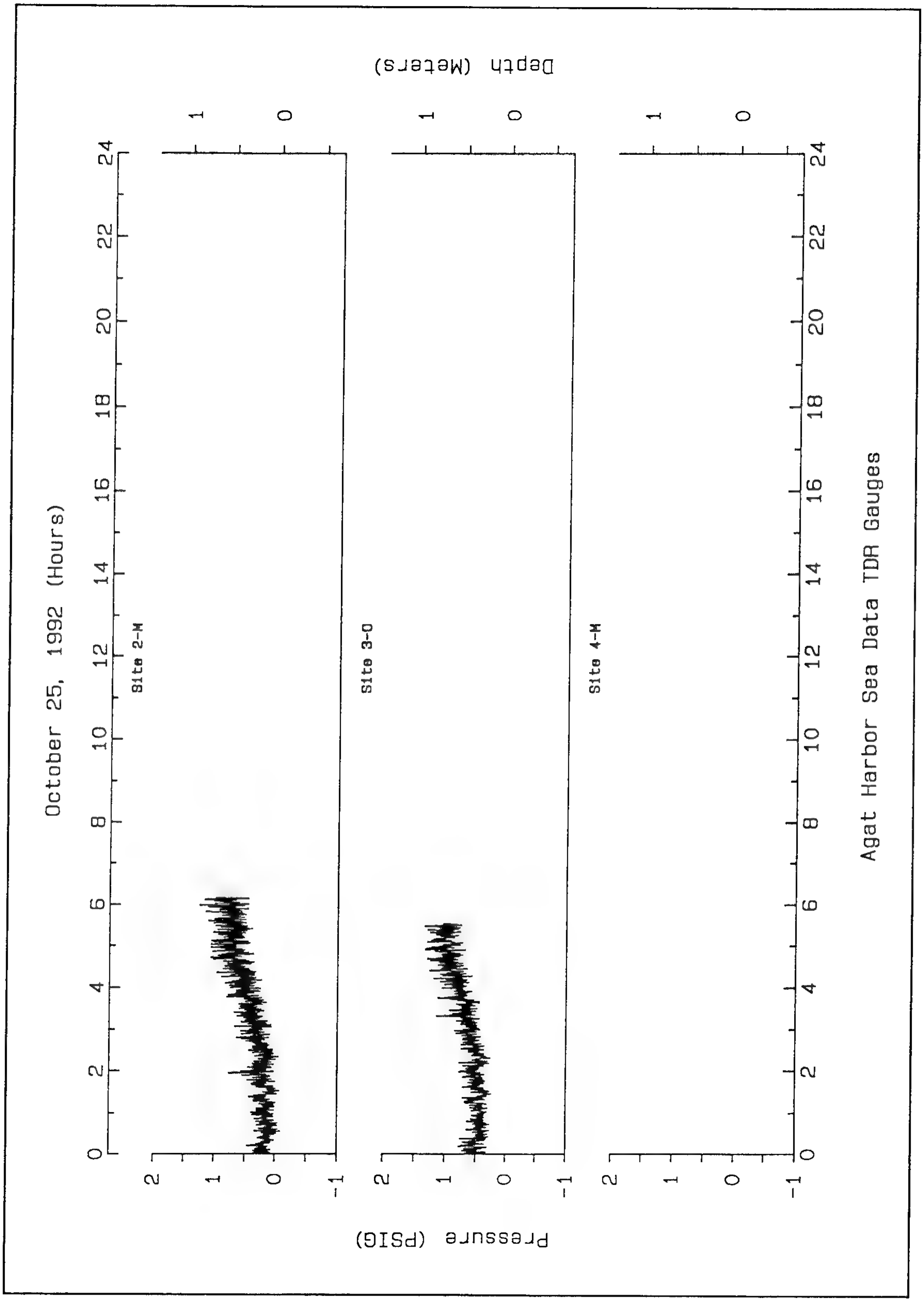
Agat Harbor Sea Data TDR Gauges
October 21, 1992 (Hours)
Site 2-M
Site 3-O
Site 4-M
Pressure (PSIG)
Depth (Meters)

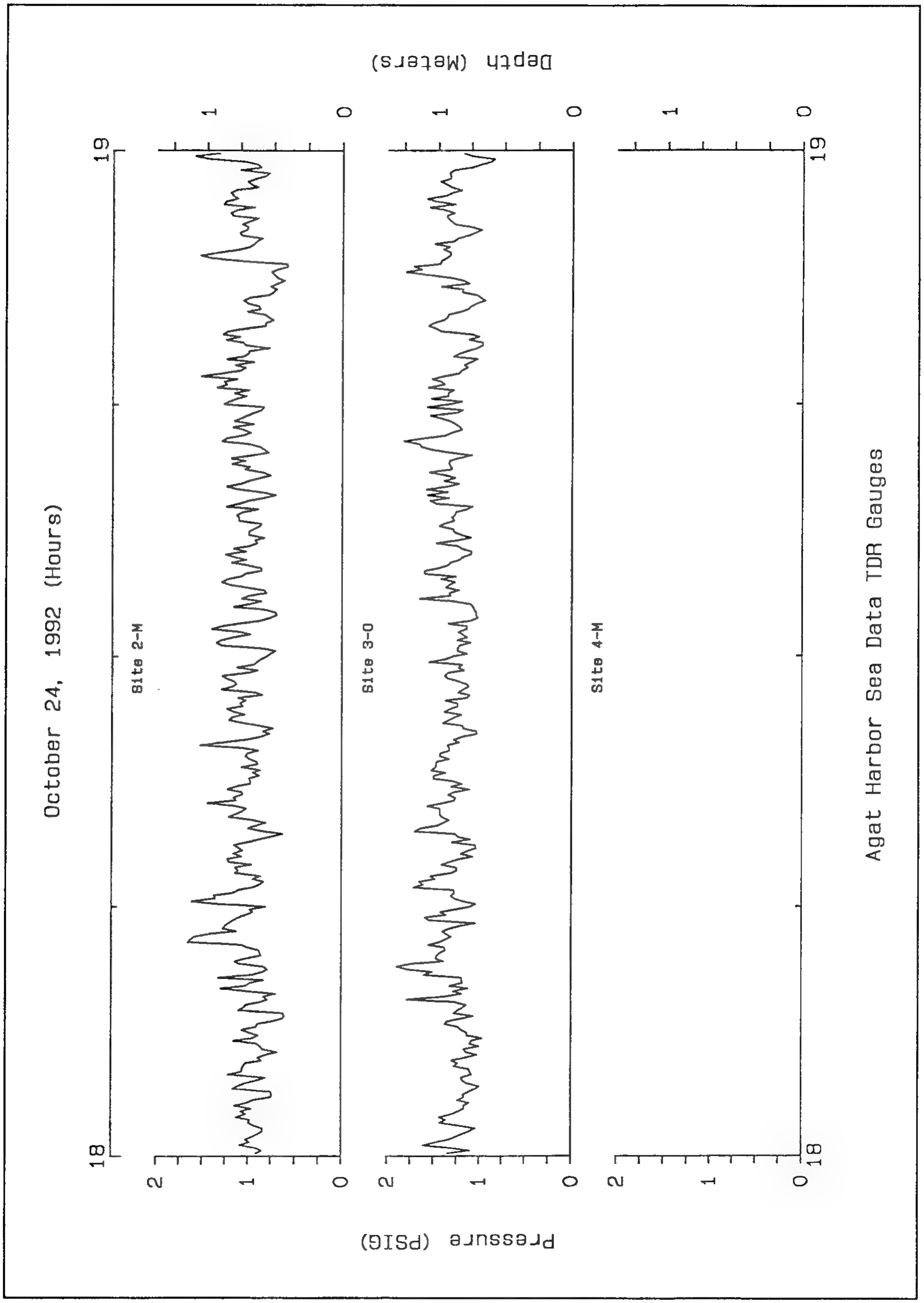

October 22, 1992 (Hours)
Site 2-M
Site 3-O
Site 4-M
Pressure (PSIG)
Depth (Meters)
Agat Harbor Sea Data TDR Gauges

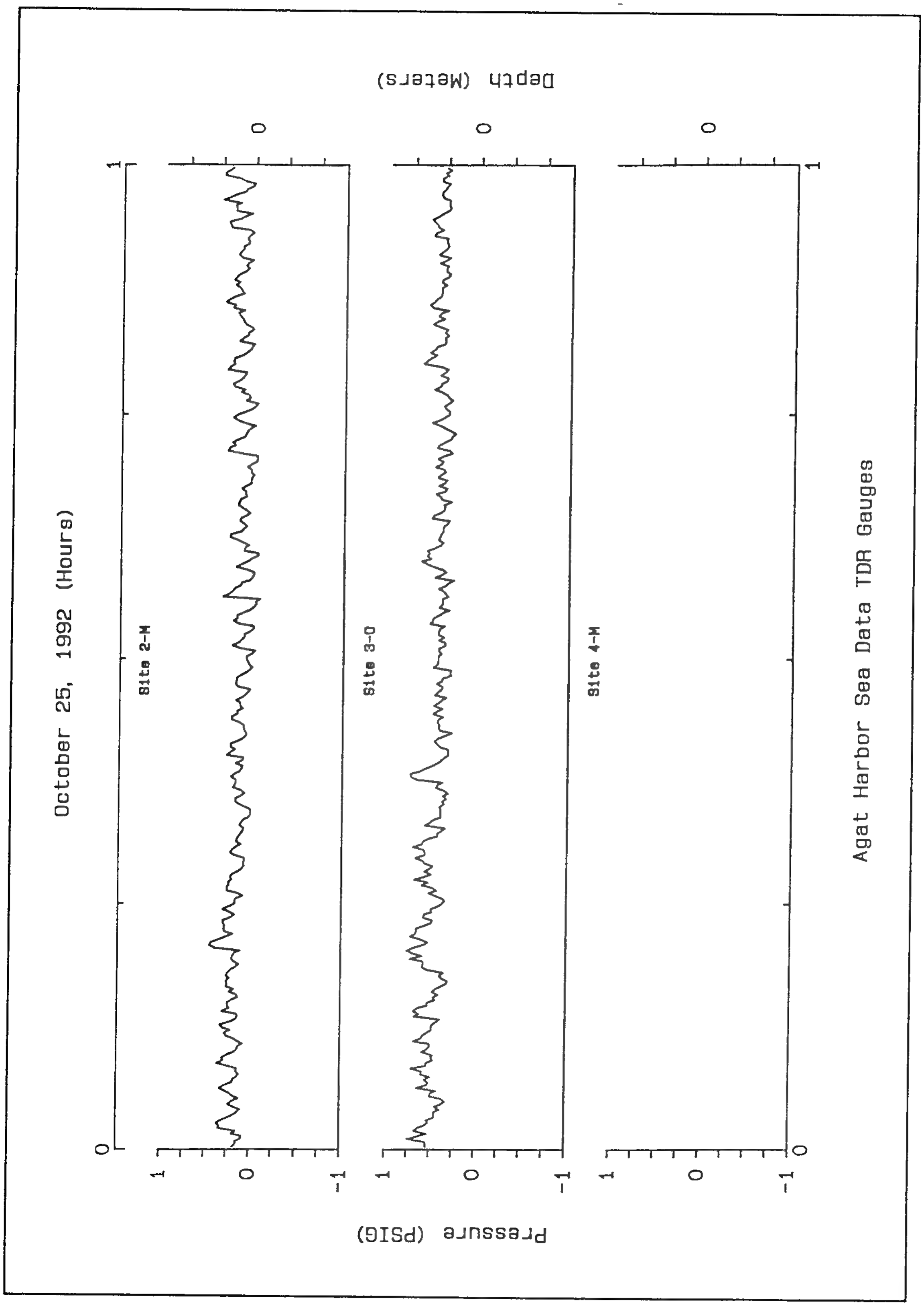


October 23, 1992 (Hours)
Site 2-M
Site 3-O
Site 4-M
Depth (Meters)
Pressure (PSIG)
Agat Harbor Sea Data TDR Gauges


Agat Harbor Sea Data TDR Gauges
October 24, 1992 (Hours)
Site 2-M
Site 3-O
Site 4-M
Pressure (PSIG)
Depth (Meters)


October 25, 1992 (Hours)
Site 2-M
Site 3-O
Site 4-M
Pressure (PSIG)
Depth (Meters)
Agat Harbor Sea Data TDR Gauges


October 24, 1992 (Hours)
Site 2-M
Site 3-O
Site 4-M
Pressure (PSIG)
Depth (Meters)
18
19
0
1
2
Agat Harbor Sea Data TDR Gauges


Agat Harbor Sea Data TDR Gauges
October 25, 1992 (Hours)
Pressure (PSIG)
Depth (Meters)
Site 2-M
Site 3-O
Site 4-M
1
0
-1
0
1

Attachment B

Agat Harbor Current Study
Eulerian Current Measurements
Second Deployment

October 20, 1992
File: 4400.66

Date	Time	Station Number	Current* Speed (cm/sec)	Wind Speed (mph)	Wind Direction (Deg Mag)	Minimum Water Depth (Ft.)	Maximum Water Depth (Ft.)
10-20-92	1050	1-Inner	0.01	20	090	1.67	1.75
10-20-92	1035	1-Outer	0.06	20	090	2.08	2.17
10-20-92	0945	2-Inner	0.12	15	040	1.17	1.33
10-20-92	1003	2-Middle	0.04	15	040	1.67	1.75
10-20-92	1015	2-Outer	0.51	15	040	1.58	1.92
10-20-92	0910	3-Inner	To Shallow	10	045	--	--
10-20-92	0920	3-Outer	To Shallow	10	045	--	--
10-20-92	0840	4-Inner	0.01	5	045	2.42	2.67
10-20-92	0815	4-Middle	0.09	5	045	2.17	2.42
10-20-92	0830	4-Outer	0.03	5	045	2.42	2.67
10-23-92	1520	3-Inner	7.64	< 5	150	3.58	5.08
10-23-92	1448	4-Inner	30.80	< 5	150	3.83	5.00

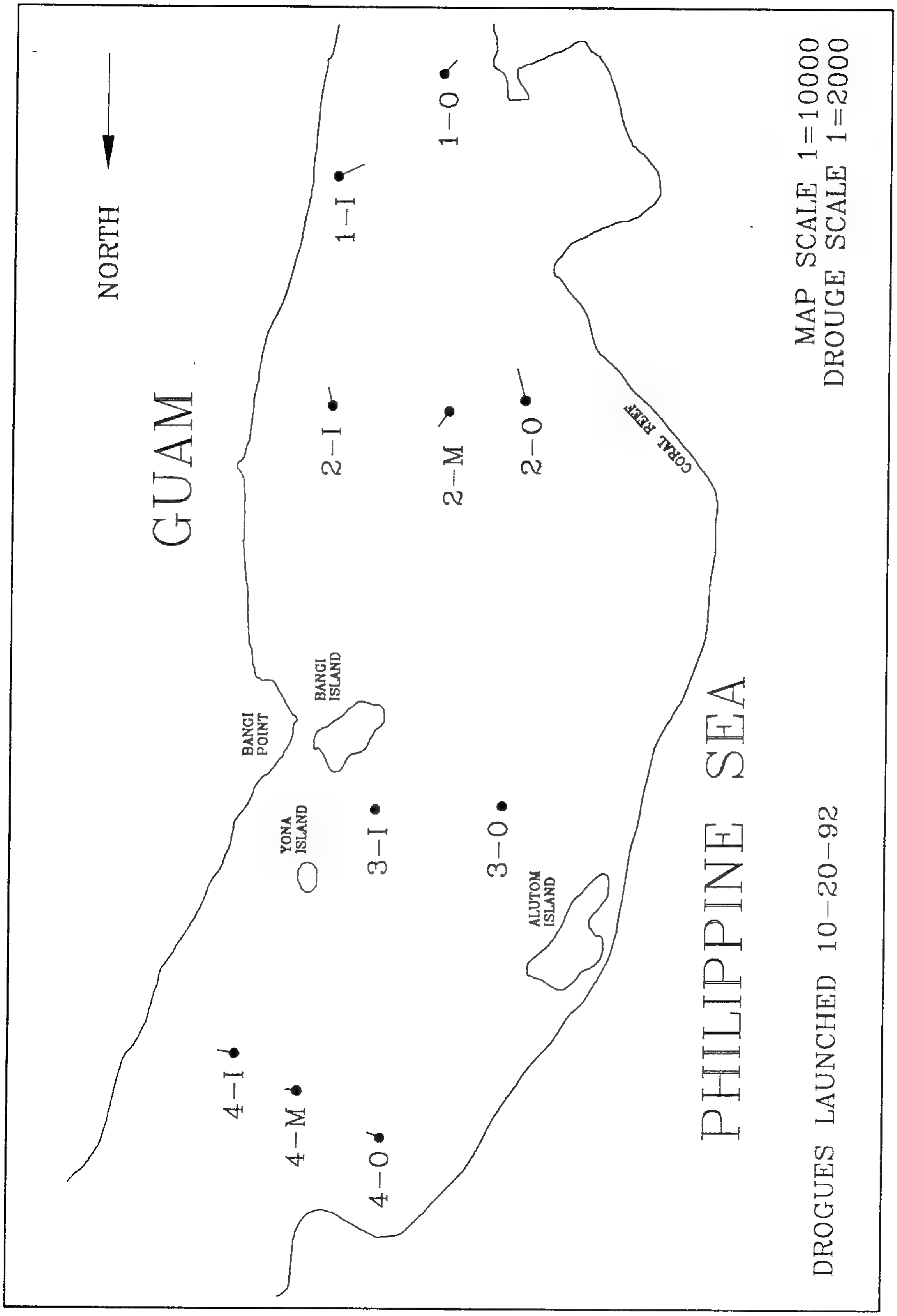
* Note: Current meter starting rotor threshold is approximately 10 cm/sec.

Attachment C

Agat Harbor Current Study
Lagrangian Current Measurements
Second Deployment

October 20, 1992
File: 4400.66

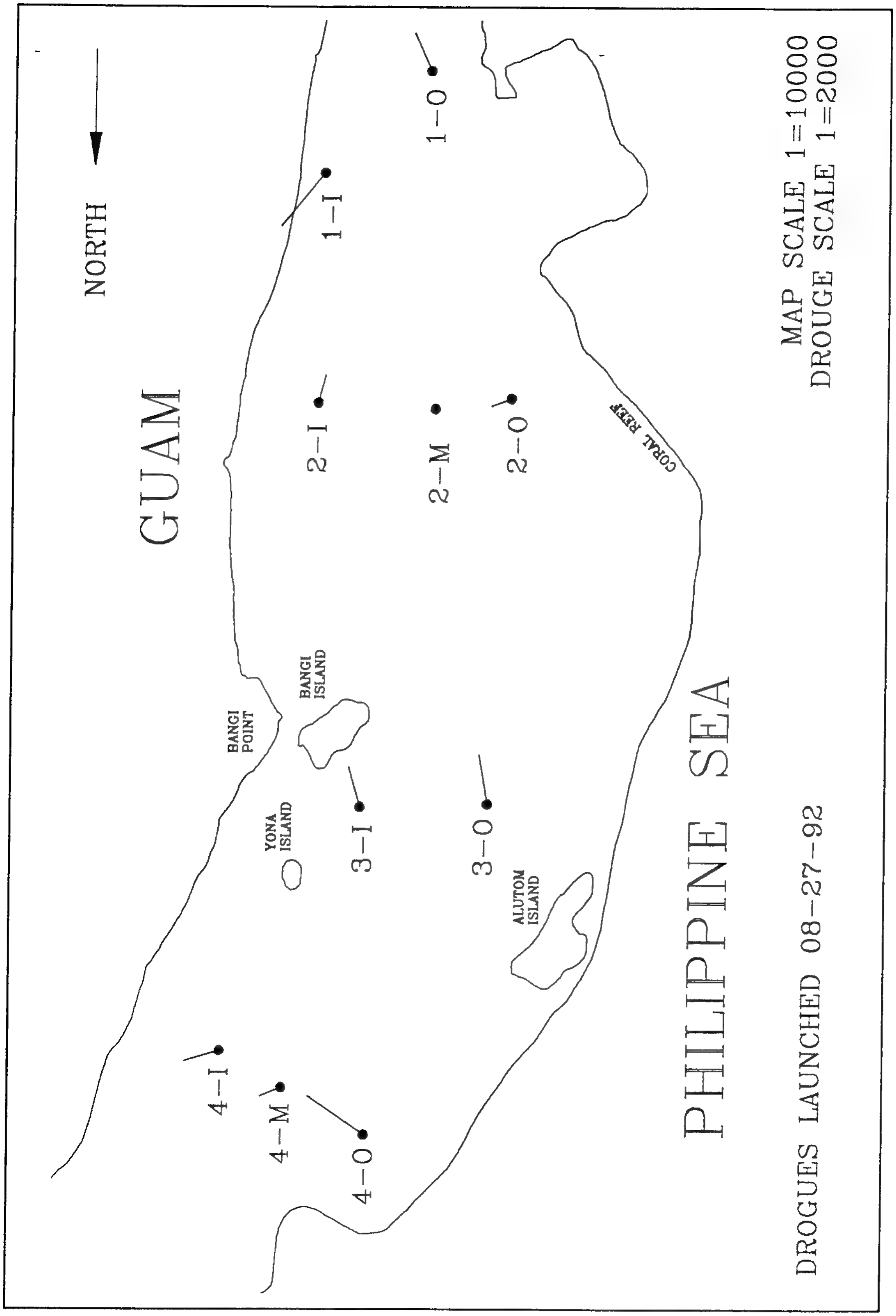
Date	Time	Station Number	Drift Drogue Time from Release (Min)	Drift Drogue Direction (Deg Mag)	Drift Drogue Approximate Distance (Feet)
10-20-92	1050	1-Inner	0.5	240	6
			1.0	240	12
			1.5	245	18
			2.0	245	22
			2.5	245	30
10-20-92	1035	1-Outer	0.5	250	4
			1.0	235	8
			1.5	230	12
			2.0	220	15
			2.5	220	20
10-20-92	0945	2-Inner	0.5	115	4
			1.0	135	6
			1.5	150	10
			2.0	160	15
			2.5	165	20
10-20-92	1003	2-Middle	0.5	055	4
			1.0	040	8
			1.5	030	12
			2.0	035	15
			2.5	035	20
10-20-92	1015	2-Outer	0.5	165	8
			1.0	170	15
			1.5	170	25
			2.0	170	30
			2.5	165	35
10-20-92	0910	3-Inner		*** To Shallow ***	
10-20-92	0920	3-Outer		*** To Shallow ***	
10-20-92	0840	4-Inner	0.5	080	6
			1.0	085	8
			1.5	090	12
			2.0	095	15
			2.5	100	18
10-20-92	0815	4-Middle	0.5	090	4
			1.0	080	6
			1.5	088	7
			2.0	094	10
			2.5	095	12
10-20-92	0830	4-Outer	0.5	070	4
			1.0	070	8
			1.5	090	10
			2.0	100	12
			2.5	115	15
10-23-92	1520	3-Inner	0.5	065	7
			1.0	095	12
			1.5	090	40
10-23-92	1448	4-Inner	0.5	020	30


NORTH
GUAM
PHILIPPINE SEA
MAP SCALE 1=10000
DROUGE SCALE 1=2000
DROGUES LAUNCHED 10-20-92
CORAL REEF
BANGI POINT
BANGI ISLAND
YONA ISLAND
ALUTOM ISLAND
1-O
1-I
2-I
2-M
2-O
3-I
3-O
4-I
4-M
4-O

Agat Harbor Current Study
Lagrangian Current Measurements - First Deployment

August 27, 1992
File: 4400.66

Date	Time	Station Number	*********** Drift Drogue ************ Time from Release (Min)	Direction (Deg Mag)	Approximate Distance (Feet)
08-27-92	1455	1-Inner	0.5	030	15
			1.0	025	25
			1.5	030	40
			2.0	030	60
			2.5	040	75
08-27-92	1443	1-Outer	0.5	140	8
			1.0	150	15
			1.5	155	25
			2.0	155	35
			2.5	155	45
08-27-92	1345	2-Inner	0.5	195	10
			1.0	195	15
			1.5	195	20
			2.0	195	25
			2.5	195	30
08-27-92	1405	2-Middle		*** To Shallow ***	
08-27-92	1420	2-Outer	0.5	030	8
			1.0	040	15
			1.5	060	15
			2.0	070	20
			2.5	070	23
08-27-92	1530	3-Inner	0.5	160	8
			1.0	158	15
			1.5	158	25
			2.0	162	33
			2.5	164	45
08-27-92	1555	3-Outer	0.5	165	8
			1.0	172	15
			1.5	170	22
			2.0	168	40
			2.5	170	55
08-27-92	1633	4-Inner	0.5	050	5
			1.0	075	10
			1.5	068	20
			2.0	066	30
			2.5	074	40
08-27-92	1655	4-Middle	0.5	055	5
			1.0	072	10
			1.5	068	12
			2.0	064	15
			2.5	068	25
08-27-92	1707	4-Outer	0.5	115	10
			1.0	125	25
			1.5	122	35
			2.0	122	60
			2.5	124	75


NORTH
GUAM
1-O
1-I
2-I
2-M
2-O
CORAL REEF
BANGI POINT
BANGI ISLAND
YONA ISLAND
3-I
3-O
ALUTON ISLAND
4-I
4-M
4-O
PHILIPPINE SEA
MAP SCALE 1=10000
DROUGE SCALE 1=2000
DROGUES LAUNCHED 08-27-92

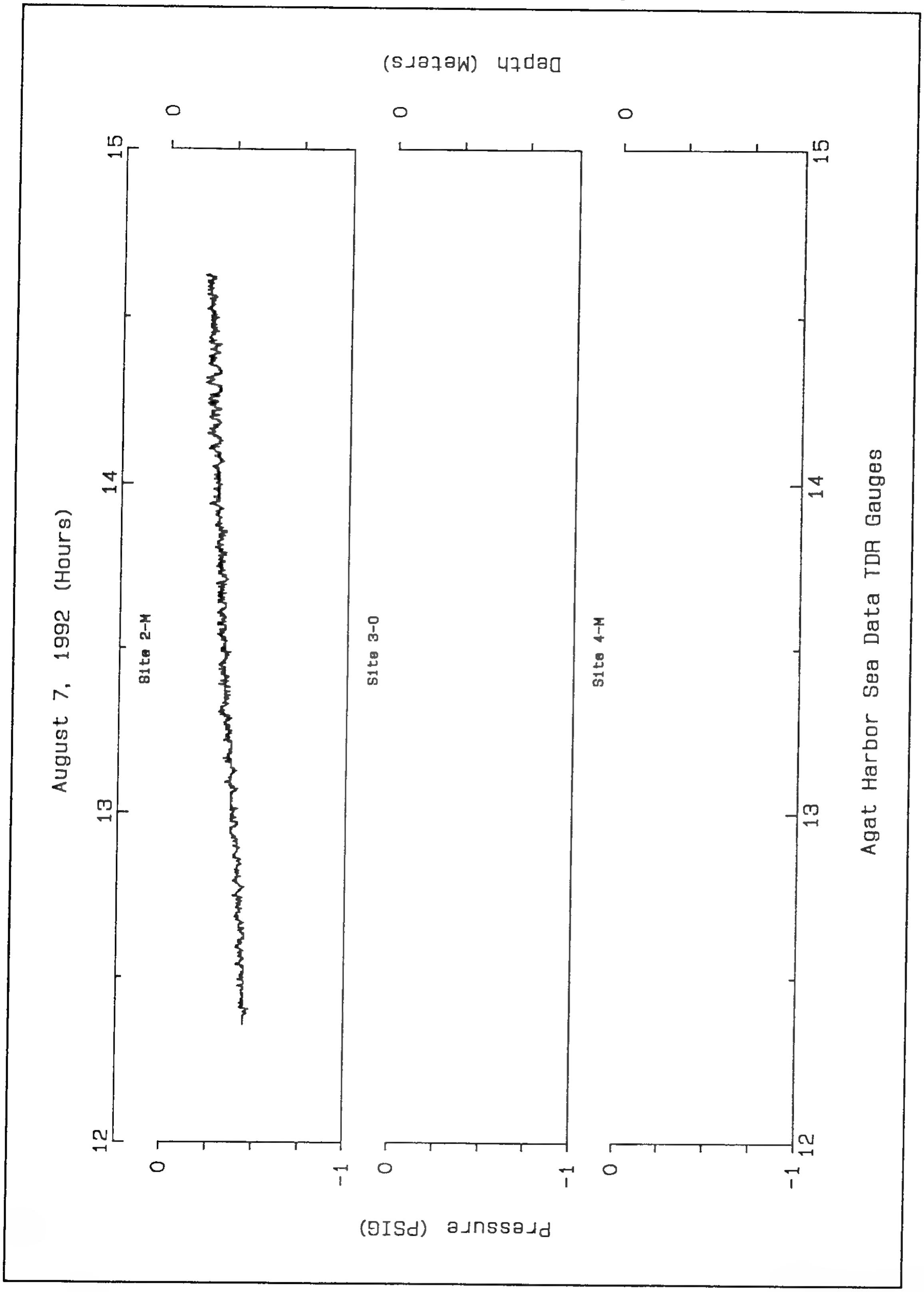
Attachment D

Agat Harbor Current Study
Eulerian Current Measurements
Dry Run Deployment

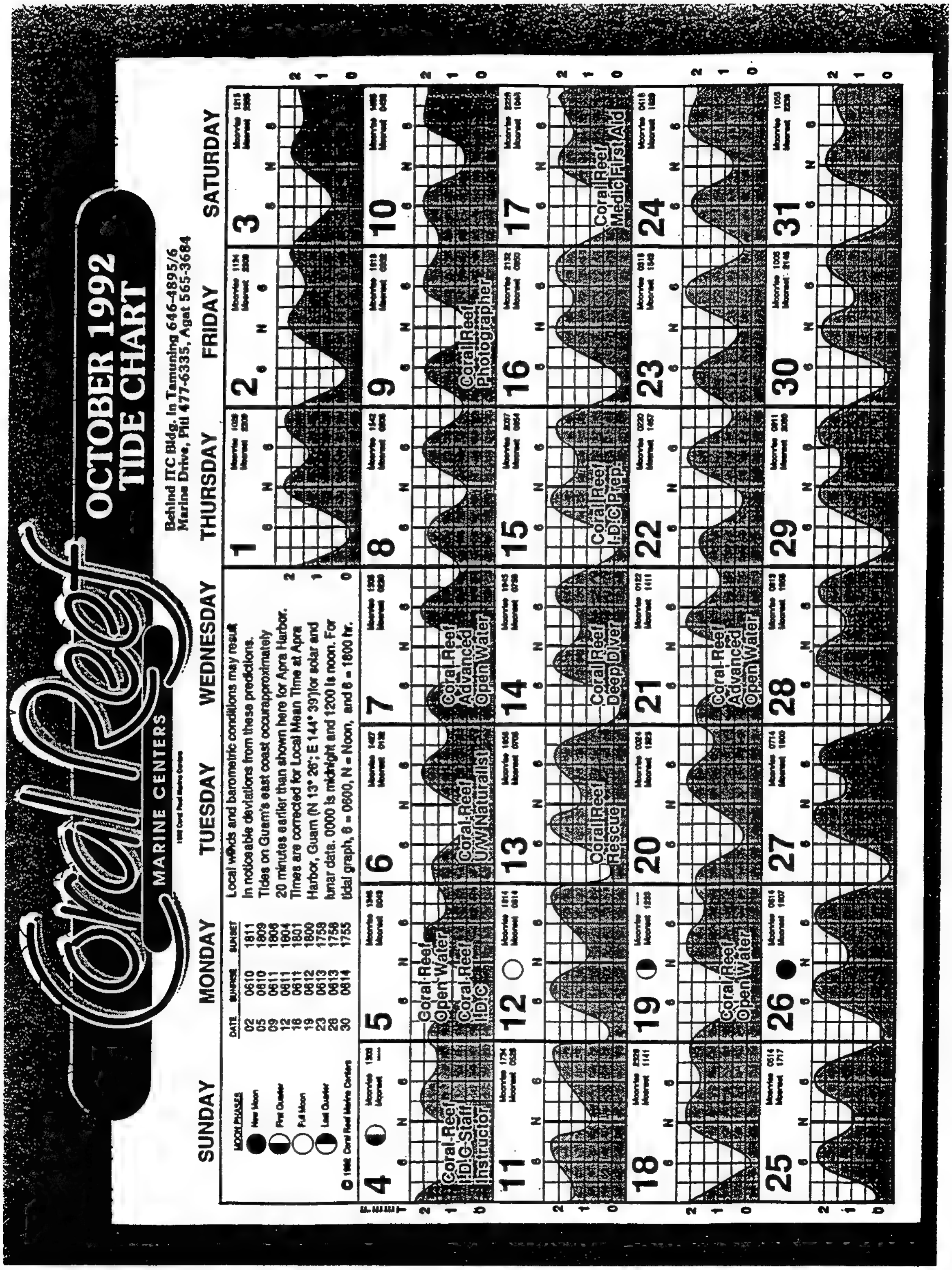
August 7, 1992
File: 4400.66

Date	Time	Station Number	Current* Speed (cm/sec)	Wind Speed (mph)	Wind Direction (Deg Mag)	Minimum Water Depth (Ft.)	Maximum Water Depth (Ft.)
08-07-92	1158	2-Inner	0.01	< 5	130	1.08	1.17
08-07-92	1220	2-Middle	0.52	< 5	120	2.25	2.33
08-07-92	1235	2-Outer	0.25	< 5	130	2.58	2.75

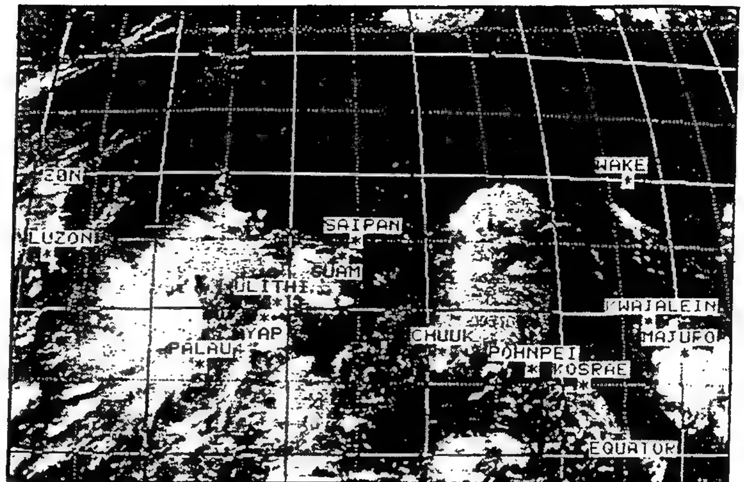
* Note: Current meter starting rotor threshold is approximately 10 cm/sec.


Agat Harbor Sea Data TDR Gauges
August 7, 1992 (Hours)
Site 2-M
Site 3-O
Site 4-M
Pressure (PSIG)
Depth (Meters)
12
13
14
15
0
-1

Attachment E



Coral Reef
MARINE CENTERS
OCTOBER 1992
TIDE CHART
Behind ITC Bldg. in Tamuning 646-4895/6
Marine Drive, Piti 477-6335, Agat 565-3684
SUNDAY
MONDAY
TUESDAY
WEDNESDAY
THURSDAY
FRIDAY
SATURDAY
Local winds and barometric conditions may result in noticeable deviations from these predictions.
Tides on Guam's east coast occur approximately 20 minutes earlier than shown here for Apra Harbor.
Times are corrected for Local Mean Time at Apra Harbor, Guam (N 13° 26'; E 144° 39') for solar and lunar data. 0000 is midnight and 1200 is noon. For tidal graph, 6 = 0600, N = Noon, and 6 = 1800 hr.
FEET
Coral Reef Advanced Open Water
Coral Reef Photographer
Coral Reef I.D.C Prep.
Coral Reef Medic First Aid
Coral Reef Deep Diver
Coral Reef Rescue
Coral Reef Open Water



Typhoon Angela is located near 12.8N 116.5E and is moving southwest at 5 knots. Tropical strom Brian is located near 10.9N 154.8E or 705 miles east of Guam and is moving west-northwest at 12 knots. Tropical depression 26W is located at 10.9N 132.2E 264 miles northwest of Palau moving west at 8 knots. Partly cloudy to mostly cloudy skies with isolated rainshowers and thundershowers prevail throughout the remainder of the forecast area.

Batten down the hatches, mates

ISLAND AND MARINE WEATHER FORECAST FOR GUAM

Today: Mostly cloudy with widely scattered moderate showers and isolated afternoon thundershowers. Winds light and variable, becoming northerly at 10 to 15 mph in the afternoon with gusts to 20 mph in showers., with gusts to 25 mph. Seas moderate 4 to 6 feet building 6 to 8 feet. Surf 5 to 8 feet building 7 to 10 feet on northwestern clockwise through southern exposures and 3 to 5 feet elsewhere. High temperature in the upper 80s.

Tonight: Mostly cloudy with widely scattered moderate showers. Winds northerly 10 to 15 mph with gusts to 25 mph near showers. Seas moderate to rough 6 to 9 feet. Surf hazardous 7 to 10 feet on northwestern clockwise through southern exposures and 4 to 6 feet elsewhere. Low temperature in the mid 70s.

OUTLOOK TOMORROW: Cloudy with intermittent rain, numerous rainshowers, isolated thundershowers, destructive winds of 110 gusting to 130 mph by noon and hazardous surf conditions.

SUNRISE-SUNSET

Sunrise today 6:12 a.m.; Sunset 6:00 p.m.; Sunrise tomorrow 6:12 a.m.

MOONRISE-MOONSET

Moonrise today N/A; Moonset 12:33 a.m.; Moonrise tomorrow 12:24 p.m.

HIGH-LOW TIDES

Low tides: 0.0 feet at 6:44 a.m., 1.6 feet at 8:01 p.m.

High tides: 2.2 feet at 2:33 a.m., 1.9 feet at 12:24 p.m.

RAINFALL

NAS Agana recorded 0.35 of an inch of rainfall yesterday, raising the monthly total to 5.36 inches.

TEMPERATURES

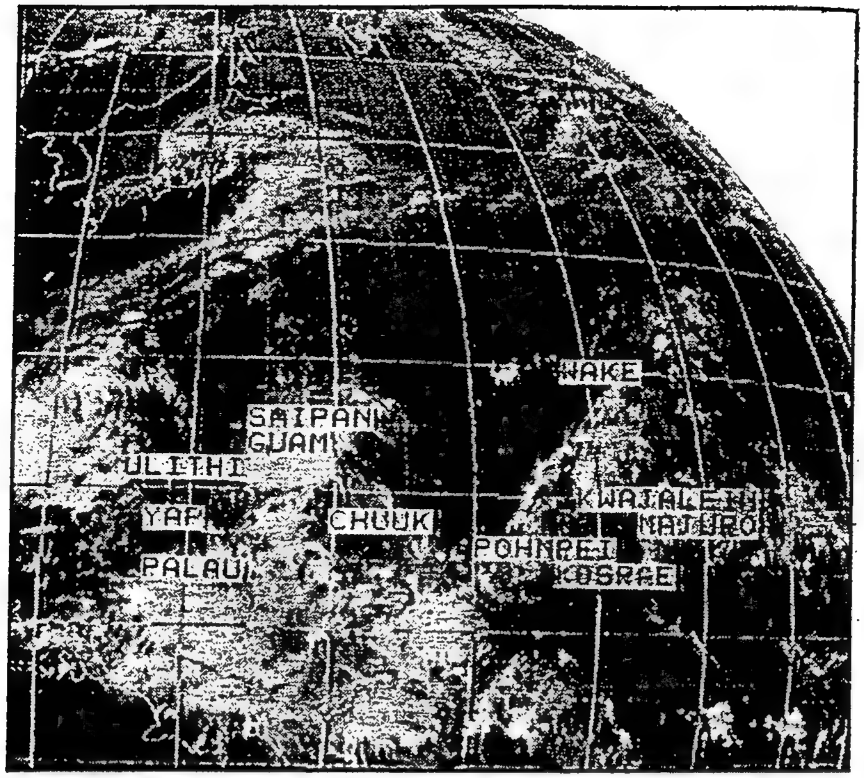
Maximum temperature yesterday 89, minimum 77.

For an updated weather forecast call 117, marine forecast 343-2991, or listen to NOAA weather radio WXM85 on VHF frequency 162.40 MHz (channel 2).

PACIFIC TEMPERATURES

Saipan	84	Partly cloudy
Palau	85	Cloudy
Yap	82	Cloudy
Chuuk	86	Cloudy
Pohnpei	[illegible]	Rainshowers
Majuro	Not available	
Honolulu	Not available	
San Diego	68	Partly cloudy
Los Angeles	65	Haze
San Francisco	63	Partly cloudy
Portland	61	Cloudy
Seattle	58	Cloudy
Seoul	61	Partly cloudy
Sydney	63	Rain
Manila	84	Haze
Hong Kong	75	Partly cloudy
Singapore	[illegible]	Haze
Taipei	72	Mostly sunny
Tokyo	63	Fog

Monday, October 19, 1992



At 7:00 p.m. Typhoon Brian is located near 12.6 north 146.4 east approximately 124 statute miles southeast of Guam. Maximum sustained winds are 100 mph gusting to 120 mph. Typhoon Colleen is located near 14.3 north 129.4 east moving west-northwest at 6 mph. A weak circulation lacated near Kwajalein is producing scattered rainshowers from Pohnpei to Wake

ISLAND AND MARINE WEATHER FORECAST FOR GUAM

Updated information not available as of press time.

SUNRISE-SUNSET

Sunrise today 6:12 a.m.; Sunset 5:59 p.m.; Sunrise tomorrow 6:12 a.m.

MOONRISE-MOONSET

Moonrise today 2:22 a.m.; Moonset 2:11 p.m.; Moonrise tomorrow 2:20 p.m.

HIGH-LOW TIDES

Low tides: 0.3 feet at 9:04 a.m., 1.0 feet at 10:22.

High tides: 1.9 feet at 2:07, 2.3 feet at 4:13.

RAINFALL

NAS Agana recorded N/A inches of rainfall yesterday, raising the monthly total to inches.

TEMPERATURES

Maximum temperature yesterday N/A, minimum N/A.

For an updated weather forecast call 117, marine forecast 343-2991, or listen to NOAA weather radio WXM85 on VHF frequency 162.40 MHz (channel 2).

PACIFIC TEMPERATURES

Saipan	74	Cloudy
Palau	86	Partly cloudy
Yap	77	Showers
Chuuk	86	Partly cloudy
Pohnpei	80	Showers
Majuro	88	Mostly sunny
Honolulu	87	Mostly sunny
San Diego	69	Sunny
Los Angeles	67	Haze
San Francisco	68	Sunny
Portland	70	Mostly cloudy
Seattle	63	Cloudy
Seoul	54	Partly cloudy
Sydney	59	Partly cloudy
Manila	79	Haze
Hong Kong	81	Mostly sunny
Singapore	79	Haze
Taipei	70	Mostly cloudy
Tokyo	63	Showers

Wednesday, October 21, 1992

Brian lost power while Guam awaited blast

By LINDA AUSTIN
and FRALE OYEN
Daily News Staff

Maybe there's no fooling Mother Nature, but she sure can fool us.

Typhoon Brian was predicted to slam Guam in much the same fashion Typhoon Omar did seven weeks ago — big, mean and destructive. Island residents boarded up, packed it in and waited for the blast — and waited and waited and waited — while Brian stalled off the coast and burned itself out.

"At the time we were getting satellite readings, it was accurate ... even the radar," Civil Defense Director Joe Terlaje said about the Brian forecasts. "(Brian) was stationary so many hours (about 12) ... it probably burned itself out."

Typhoon Brian was a "typhoon but not a real intense typhoon as Omar," Lt. Col. Chip Guard, director of the Joint Typhoon Warning Center, said at about 4 p.m.

Omar, which hit Guam Aug. 28, packed sustained winds of 120 mph with gusts of 150 mph.

Brian, which passed from Talofofo Bay sometime between 9:30 a.m. and 9:45 a.m. yesterday to Naval Station at 1:30 p.m., is now making its way across the Philippine Sea.

As it left Guam, Brian was estimated to be packing sustained winds of 100 mph with gusts of 125 mph, Guard said.

Weather watchers say Brian had maximum sustained winds of 85 mph with gusts of 105 mph. However, Guard warned that those figures are early estimates.

A final report on Brian's strength won't be available for another week. Until then, weather officials will be examining things such as vegetation damage, storm surges and pressure readings, Guard said.

The storm's eye, which was about eight miles across, passed over Talofofo, Santa Rita, Agat and Orote Point, Guard said. The eye, which is reported to have expanded and even broken up for a while as it passed over the southern and central parts of Guam, is also believed to have passed over parts of Merizo, Nimitz Hill and Agana.

"Well, it's better to be prepared than not prepared," Civil Defense spokesman Carl Gumataotao said. "We did great. Everything looks cheery."

"Every storm we learn lessons," said public utilities agency Director Joe Mesa. "The key lesson ... is we need generators for all our wells."

The worst aspect of Brian "was the waiting and the waiting and the waiting," Mesa added.

Still, not everyone was happy with Brian's fizzled performance.

"The surf never came," one man complained jokingly to Terlaje as he entered Civil Defense last night. "Manana. Manana."

For the Record

Weather returns to normal after brief typhoon interruption

ISLAND AND MARINE WEATHER FORECAST FOR GUAM

Today: Cloudy becoming mostly cloudy with isolated light to moderate showers. Winds westerly 10 to 15 mph. Seas moderate to rough 8 to 12 decreasing 4 to 8 feet by late morning. Surf hazardous 9 to 13 feet abating to 6 to 9 feet on all exposuresby late morning. High temperature in the low 80s.

Tonight: Mostly cloudy becoming partly cloudy with isolated early morning showers. Winds westerly 10 to 15 mph. Seas slight to moderate 3 to 5 feet. Surf 4 to 6 feet on southern clockwise through northern exposures and 2 to 3 feet elsewhere. Low temperature in the mid 70s.

OUTLOOK TOMORROW: Decreasing cloudiness and winds.

SUNRISE-SUNSET

Sunrise today 6:12 a.m.; Sunset 5:59 p.m.; Sunrise tomorrow 6:13 a.m.

MOONRISE-MOONSET

Moonrise today 2:20 a.m.; Moonset 2:57 p.m.; Moonrise tomorrow 3:18 a.m.

HIGH-LOW TIDES

Low tides: 0.1 feet at 7:54 a.m., 2.3 feet at 3:29 p.m.

High tides: 1.9 feet at 10:24 a.m., 1.3 feet at 7:21 p.m.

RAINFALL

NAS Agana recorded 5.4 inches of rainfall yesterday, raising the monthly total to 11.79 inches.

TEMPERATURES

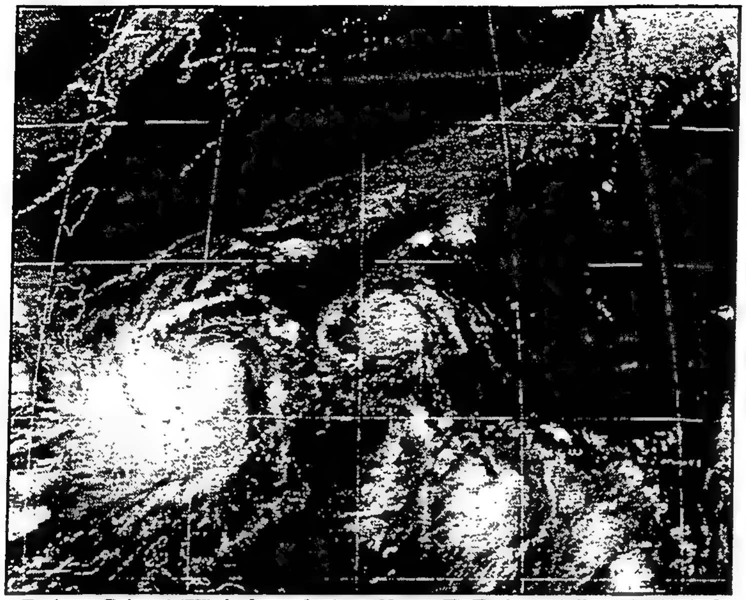
Maximum temperature yesterday 80, minimum 72.

For an updated weather forecast call 117, marine forecast 343-2991, or listen to NOAA weather radio WXM85 on VHF frequency 162.40 MHz (channel 2).

PACIFIC TEMPERATURES

Saipan	77	Rainshowers
Palau	Not available	
Yap	Not available	
Chuuk	Not available	
Pohnpei	Not available	
Majuro	Not available	
Honolulu	Not available	
San Diego	Not available	
Los Angeles	Not available	
San Francisco	Not available	
Portland	Not available	
Seattle	Not available	
Seoul	Not available	
Sydney	Not available	
Manila	Not available	
Hong Kong	Not available	
Singapore	Not available	
Taipei	Not available	
Tokyo	Not available	

Thursday, October 22, 1992



Typhoon Brian (25W) is located at 16.0N 142.3E. Typhoon Colleen (26W) is located at 13.2N 130.8E. A weak cyclonic circulation located west of Majuro is producing mostly cloudy to cloudy skies and scattered rainshowers with isolated thunderstorms from Kwajalein south to the equator. Convergent wind flow located southwest of Chuuk is producing cloudy skies with scattered rainshowers and thunderstorms. Partly cloudy skies with isolated rainshowers prevail throughout the remainder of the forecast area. Satellite photo — 10 a.m. yesterday.

Partly cloudy with southerly winds

ISLAND AND MARINE WEATHER FORECAST FOR GUAM

Today: Partly cloudy with isolated light to moderate showers. Winds southerly 10 to 20 mph. Seas slight to moderate 3 to 5 feet. Surf 4 to 7 feet on southern clockwise through northeastern exposures and 2 to 4 feet elsewhere. High temperature in the upper 80s.

Tonight: Partly cloudy with isolated light showers. Winds light and variable. Seas slight to moderate 3 to 5 feet. Surf 4 to 6 feet on southern clockwise through northeastern exposures and 2 to 4 feet elsewhere. Low temperature in the mid 70s.

OUTLOOK TOMORROW: Partly cloudy with showers

SUNRISE-SUNSET

Sunrise today 6:13 a.m.; Sunset 5:58 p.m.; Sunrise tomorrow 6:13 a.m.

MOONRISE-MOONSET

Moonrise today 3:18 a.m.; Moonset 3:43 p.m.; Moonrise tomorrow 4:16 a.m.

HIGH-LOW TIDES

Low tides: 0.6 feet at 11:11 a.m., 0.3 feet at 11:57 p.m.

High tides: 2.1 feet at 5:09 a.m., 2.4 feet at 5:30 p.m.

RAINFALL

NAS Agana recorded 0.09 of an inch of rainfall yesterday, raising the monthly total to 11.55 inches.

TEMPERATURES

Maximum temperature yesterday 91, minimum 78.

For an updated weather forecast call 117, marine forecast 343-2991, or listen to NOAA weather radio WXM85 on VHF frequency 162.40 MHz (channel 2).

PACIFIC TEMPERATURES

Saipan	82	Cloudy
Palau	86	Partly cloudy
Yap	86	Partly cloudy
Chuuk	84	Rainshowers
Pohnpei	79	Rainshowers
Majuro	85	Mostly cloudy
Honolulu	86	Mostly cloudy
San Diego	69	Mostly cloudy
Los Angeles	68	Haze
San Francisco	65	Mostly sunny
Portland	60	Cloudy
Seattle	57	Partly cloudy
Seoul	55	Fog
Sydney	55	Mostly sunny
Manila	77	Haze
Hong Kong	73	Sunny
Singapore	79	Haze
Taipei	72	Mostly sunny
Tokyo	61	Sunny

Friday, October 23, 1992

Appendix B Performance Critique

Offshore System

Terrestrial hazards

The NDBC buoy was deployed at Site 1A on 17 September 1990 and designated station 52009. Within 10 days of deployment, a hatch was unbolted and the internal Loran unit taken. The unit was replaced and the buoy remained in service through December 1990, when it was lost during Typhoon Russ. Lack of funds prevented replacement of the buoy until the next fiscal year. A second buoy was deployed in December 1991 at a position to the north of the island (Site 1B) on the advice of the Guam Department of Fisheries, to avoid the route to and from the popular fishing ground south southwest of the island. This feedback from the local community seemed effective, as there were no further indications of tampering or vandalizing at the new site. However, operation was affected by circumstances literally beyond the reach of the project.

Celestial hazards

In 1992, the western GOES satellite began exhibiting eccentricities in its orbit, periodically placing it below the buoy's horizon. Though both the buoy and the satellite were still operational, each orbital dip caused transmission gaps for station 52009, the westernmost GOES-reporting buoy in operation. Since its problem was just part of a significant crisis in the satellite sensing and communication community, the solution seemed to be awaiting the correction of the satellite's orbit. In June of 1992 the western GOES satellite was deactivated, and the eastern GOES repositioned far enough westward to provide coverage of the west coast of the United States, but not of Guam. NDBC immediately began design and construction of a portable, line-of-sight receiver and data logger that could pick up the signals from the buoy's still-functioning transmitter. Near-real-time telemetry would be replaced by monthly downloading and mailing of the data, similar to the capture scheme used for the nearshore system. In October of 1992, this unit was placed at the National

Weather Service office in Guam to obtain the transmissions directly. This "fix" solved the problem for the duration of the study, but in the interim, Typhoon Omar visited Guam and left unmeasured.

Discussion

While some buoys have capsized in extremely steep waves, complete loss of a moored NDBC buoy is very unusual, leading to speculation that another tampering incident may have affected the hull's integrity. NDBC had no prior experiences with tampering, probably because buoys are used in relatively deep water, and deep water tends to be offshore, beyond the reach of the high-volume, recreational boating community, in the continental United States. Locks are impractical in this environment, but a simple solution to this problem is use of atypical fasteners on hatches. Most boaters carry tools for hex-head bolts, but not many have a complete set of the newer, specialty wrenches. With a few spectacular exceptions, satellite communication has proven reliable, so there is little chance of a repeat of the telemetry problem. In any case, NDBC now has a working solution for this eventuality in the line-of-sight receiver/logger.

Nearshore System

Problems

A late start. Important data that might have been captured by the nearshore system, including measurements of Typhoon Russ, were missed because of delays in activation. Monitoring could have begun upon completion of the harbor, but the event on the critical path was completion of the power supply for the administration building. As it turned out, when activated, the system suffered from failures of software, hardware, and procedure that combined synergistically to thwart diagnosis and repair of the individual causes. The offshore buoy, being completely self-contained, was not affected by the project construction schedule.

Connectivity. The first significant problem was inability to establish a modem connection from the Coastal Engineering Research Center (CERC) over the available commercial telephone lines. This problem was not evident during setup, while a system operator was controlling the Vax locally, but remote access and control of the system from CERC proved impossible using the long distance voice lines. This precluded remote data retrieval, but would have been less serious if the backup feature - local storage on tape - had functioned as designed. The Vax software was designed to automatically analyze the pressure time series and save the energy spectra. When the first tapes began arriving, they were full but unreadable. A combination of extremely noisy signals, a software error in the Vax programs controlling data file management, and concurrent problems with the Interbase software on the CERC

mainframe that was supposed to manage the processed records made for a diagnostic puzzle of circular complexity. Without on-line access to the Vax by the programmer, different solutions had to be mailed to the local contractor for installation and testing. Though capable with electronics and PC's, the maintenance contractor was unfamiliar with the Vax and its VMS operating system, further delaying solution.

Discussions with the U.S. Navy revealed the key to the communication requirements: an Internet connection to a local (Guam) server; from there, dedicated data phone lines to the modem. Initiation of the contract for these services began in May of 1991. As did every administrative detail of the study, from issuing travel orders to accounting for government property, from ordering a phone line to sending faxes, the contract experienced delays. Guam's uniqueness, remoteness, and status as a territory outside the continental United States (OCONUS) meant normal bureaucratic procedures weren't applicable, and decisions were required at higher managerial levels. For example, the contract for the Internet link was not awarded for 18 months.

Getting grounded. Contractual issues also delayed the diagnosis of an unforseen environmental hazard that caused significant problems and hardware damage throughout the study. A floating electrical ground, as high as 50 volts, plagued the Administration building and surrounding utility hardware, probably due to ground faults between the underground main power cable and its conduit.[1] The presence of a major problem in the raw data (i.e., a signal-to-noise ratio near unity) was only discovered when pressure time series from the RTU buffers were retrieved by the on-site contractor and mailed to CERC on magnetic discs. Though trained to perform this service during the installation in August of 1990, the local contractor had to wait until February 1991 to officially begin work. Because attention was focused on the other problems in recovering and analyzing valid data sets, the symptoms were not even discovered until the summer of 1991. Attempts were made to isolate the system ground from earth ground, but the extremely salty, humid environment allowed the problem to reappear frequently during the course of the study (particularly during rainy weather), resulting in excessive noise in much of the data.

By August of 1991, the software problems were resolved, the automatic analysis in the Vax was suspended, and raw data were being written to tapes and mailed monthly to CERC. In October of 1991, the Vax hard disc failed. Even housed in a climate-controlled building, an "autopsy" revealed corrosion on interior components. It was not clear if the cause was the recently discovered stray voltages, the salt-laden atmosphere, or a fatal combination of the two. Until the problem was corrected, there was a reluctance to submit the remaining back-up Vax to the same fate. It was decided to postpone replacement until a major repair/refurbishment trip could be arranged with senior technicians and programmers.

---

[1] During system installation, the author noted the use of excessive force (with a crane) to pull the main service wires through the underground conduit. It is probable that insulation was damaged in the process.

The repair trip took place in August 1992. To isolate the new Vax and the RTU electrically from the building power and ground, they were wired, ungrounded, in series to the conditioned AC power coming from the UPS. By using the battery bank as a capacitor, most of the problem was eliminated. The signals from the transducers still contained noise because it was impossible to electrically isolate the armored cables, but the situation was greatly improved. This plan meant that the UPS was now the prime power source, and not just a backup. The batteries were always powering the system, and were continuously recharged by the main electrical service or the generator if an outage occurred. The solution later turned into a failure mode, but it served the purpose of protecting the hardware - the second Vax operated for the duration of the study.

Power. The UPS worked well, keeping the system operating during the frequent power outages, for the first 2 years. In fact, it was so essential that the Guam Harbor Police who manned the Administration building frequently utilized it to maintain radio and other electrical service during power outages. This added load probably contributed to its demise when the generator failed to come on when needed. The maintenance contract required periodic starting of the generator set, routine oil and filter changes, and battery fluid checks. The diesel engine itself worked well for 3 years. The first component to fail, sometime in the fall of 1992, was the electronic control module that automatically starts the generator when the service voltage drops out. Though housed in a weatherproof steel enclosure, it still suffered extensive corrosion. Since the engine worked when manually activated during testing, the problem was not detected for several months. During outages, the system worked only until the battery bank was drained. The combination of rapid discharge and slow recharge (through the smaller AC charger) may have contributed to the battery failure. In any case, the batteries deteriorated to the point that they would not power the system even when line power was available. In February 1993, the control panel and entire set of batteries were replaced.

Wired. The underwater portion of the system had relatively few problems. Two of the eleven transducers required replacement after 2 years. Of the seven submarine armored cables, five failed during the last few months of the 3-year deployment. All the cables exhibited severe corrosion where they entered the buried conduit at the shoreline, another effect of the stray voltages described earlier.

The "un-problem." The portion of the system that did work flawlessly was the RTU - the first stop for the signals and final stop-gap for data recovery. Completely solid state and sealed in a stainless steel water-tight enclosure, the RTU had been designed for remote, untended operation in hostile environments. Early concerns that the tropical heat would prove detrimental were unfounded, and there was no need to use the back-up RTU installed on-site. Many of the important, if short-term, data sets from the study were obtained through manual downloading of the RTU buffers.

Discussion

Data capture strategy

The basic strategy for capturing short, relatively rare events was continuous monitoring. Since it worked reasonably well for the offshore system, the approach appears to be valid for these circumstances, at least for a self-contained system at a single measurement site. With nine separate measurement sites, the nearshore system was logistically and economically more challenging. At the time of the study, the available technology for self-contained instruments would have limited operation to 3 or 4 months. The cost of several replacements per year at nine sites for several years was considered prohibitive. Since then, battery and memory capabilities have increased so that annual or longer deployments are practical.

The episodic approach used in the circulation study did provide water level data during one moderately energetic event, but the plan to obtain in situ current measurements was not successful. Years of experience in attempting to capture hurricane surge episodically (in the southeast United States), with only occasional success, convinced the author that successful event-triggered measurements require ample advance warning and an extremely motivated deployment team. A compromise between continuous monitoring and event-triggered deployment that may have been more effective is seasonal monitoring - the data reveal that half the year is uneventful. That approach has been successful in measuring hurricane surge in the Gulf of Mexico by the CERC Episodic Events Work Unit, though most years do not result in the coincidence of surge and working instruments.

The system design used centralized acquisition and control of networked, remote sensors. The use of a rugged, self-powered gage for the offshore system certainly was advantageous. At the time of the study, the deployment limit for available nondirectional wave gages at the desired sampling scheme was about 3 months, and the historical performance of those gages was no better than 50 percent. The only available self-contained directional gage used a bi-axial current meter that would not have been suitable for the shallow, tropical waters. The number of gages required (two for each site) and the cost associated with four change-outs each year, particularly for the gages requiring divers for retrieval, was considered prohibitive. Since that time, CERC has developed and tested the DWG-1, a self-contained directional gage using a pressure array with a 13-month deployment capability. Non-directional gages are now available commercially with similar capacity.

The data management plan was designed to allow both routine and random access for evaluation of data and system performance. Unfortunately, the design centered on custom software that had little field testing before deployment, and an uncommon (in Guam) computer and operating system. The inability to read the earlier data tapes (when the system was operational) delayed detection of the hardware failures that followed. Local capture of the data in solid state memory in the proven RTU proved very successful, as long

as the system had adequate power, and the buffers were downloaded before being overwritten. Local data storage - though several miles distant from the gage - also proved necessary for the offshore system when the telemetry link failed. On the other hand, the valuable typhoon measurements would have "gone down with the ship" without telemetry. Obviously both onboard buffers and telemetry should be combined in a redundant data capture scheme. That was the intent of the inshore system, but it failed in practice for the reasons described above.

The human dimension

Finally, the challenges of space and time (zones) should not be presumed to have surrendered to telephones and jet travel. Communication by fax became the norm due to the out-of-phase work days. Transportation cost for people and equipment added cost and time to every phase of the study, from the first site visit to the final demobilization. The solutions to these and the other problems discussed so far have focused on a systems approach, and would have been applicable had the island been uninhabited. Managerial solutions also exist that would have made better utilization of the available human resources.

In addition to the bureaucratic novelty previously mentioned, ignorance of the local customs, infrastructure and political network compounded what would have been minor problems in a similar stateside operation. The organization, including the author, failed to adequately address the needs, problems, and methods endemic to the culture upon which we relied. More time should have been invested in explaining the project to local agencies and organizations and soliciting their suggestions and help. One solution is assignment of two people, one in Guam and one in CERC, whose principal jobs are trouble-shooter and facilitator. Their role would be to transmit problems and solutions to each other and to their own organizations through frequent, perhaps even scheduled, communication. Neither person need be in a position of authority; in fact, problems would probably be discussed more openly if their role was limited to identifying problems and suggesting solutions. However, each would need to be familiar with their own system - who controls what functions, what paperwork precedes each action, etc. The investment in the labor cost of these two, say one man-year over the course of the project, would likely have done more for the success of the project than an equal expenditure in hardware.

Appendix C
Summary Statistics of Incident Wave Conditions

MEAN Hm0(METRES) BY MONTH AND YEAR
NDBC BUOY 52009 (13.20N 144.50)

MONTH

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
1990	.	.	.	.	.	.	.	.	1.0	1.3	1.9	1.8	1.6
1991	.	.	.	.	.	.	.	.	.	.	.	2.0	2.0
1992	2.4	1.8	2.1	1.4	1.2	1.3	.	.	1.4	1.9	2.4	2.4	1.9
1993	2.3	2.1	1.9	1.7	1.3	1.0	1.1	1.8	1.2	1.6	1.9	2.4	1.7
1994	1.9	1.9	2.1	1.3	.	.	.	.	.	.	.	.	1.9
MEAN	2.2	1.9	2.1	1.5	1.2	1.1	1.1	1.8	1.2	1.6	2.0	2.2	

LARGEST Hm0(METRES) BY MONTH AND YEAR
NDBC BUOY 52009 (13.20N 144.50)

MONTH

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1990	.	.	.	.	.	.	.	.	1.7	3.3	4.5	9.8
1991	.	.	.	.	.	.	.	.	.	.	.	3.1
1992	4.3	3.8	2.9	2.2	2.2	2.3	.	.	2.1	4.0	5.9	4.0
1993	3.5	4.0	3.1	2.3	2.3	1.8	1.8	4.2	4.0	2.6	3.3	3.5
1994	3.4	3.3	4.1	2.2	.	.	.	.	.	.	.	.

STATISTICS FOR NDBC BUOY 52009 (13.20N 144.50)

THE MEAN SIGNIFICANT WAVE HEIGHT(METRES)=	1.8
THE MEAN PEAK WAVE PERIOD (SECONDS)=	9.5
THE MOST FREQUENT 22.5(CENTER) DIRECTION BAND (DEGREES)=	67.5
THE STANDARD DEVIATION OF Hm0(METRES)=	0.7
THE STANDARD DEVIATION OF TP(SECONDS)=	1.9
THE LARGEST Hm0(METRES)=	9.8
THE TP(SECONDS)ASSOC. WITH THE LARGEST Hm0=	14.3
THE PEAK DIRECTION (DEGREES) ASSOC. WITH THE LARGEST Hm0=	112.0
THE DATE OF LARGEST Hm0 OCCURRENCE IS	90122014

BUOY STATION 52009 13.20 N 144.50 AZIMUTH(DEGREES) = 0.0
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	<6.9	6.9-8.0	8.1-8.7	8.8-9.5	9.6-10.5	10.6-11.7	11.8-13.3	13.4-15.3	15.4-18.1	18.2-LONGER	
0.0-0.9	7	44	74	155	244	222	44	29	.	.	819
1.0-1.9	81	199	496	1177	1406	1443	1266	399	29	.	6496
2.0-2.9	22	170	199	399	681	1051	607	429	29	.	3587
3.0-3.9	.	7	29	74	88	96	185	111	51	.	641
4.0-4.9	.	.	.	7	7	.	7	.	.	.	21
5.0-5.9	.	.	.	.	7	.	.	.	.	.	7
6.0-6.9	.	.	.	.	.	.	.	.	.	.	0
7.0-7.9	.	.	.	.	.	.	.	.	.	.	0
8.0-8.9	.	.	.	.	.	.	.	.	.	.	0
9.0-9.9	.	.	.	.	.	.	.	.	.	.	0
10.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	110	420	798	1812	2433	2812	2109	968	109	0	

MEAN Hm0(M) = 1.8 LARGEST Hm0(M)= 5.3 MEAN TP(SEC)= 10.8 NO. OF CASES= 1565.

BUOY STATION 52009 13.20 N 144.50 AZIMUTH(DEGREES) = 22.5
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	<6.9	6.9-8.0	8.1-8.7	8.8-9.5	9.6-10.5	10.6-11.7	11.8-13.3	13.4-15.3	15.4-18.1	18.2-LONGER	
0.0-0.9	14	81	170	288	244	214	103	29	.	.	1143
1.0-1.9	133	370	607	1288	1673	1554	1776	740	7	.	8148
2.0-2.9	88	333	333	592	695	644	755	488	22	.	3950
3.0-3.9	14	37	37	155	66	96	14	51	.	.	470
4.0-4.9	.	.	14	7	.	7	.	.	.	.	28
5.0-5.9	.	.	.	.	.	.	.	.	.	.	0
6.0-6.9	.	.	.	.	.	.	.	.	.	.	0
7.0-7.9	.	.	.	.	.	.	.	.	.	.	0
8.0-8.9	.	.	.	.	.	.	.	.	.	.	0
9.0-9.9	.	.	.	.	.	.	.	.	.	.	0
10.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	249	821	1161	2330	2678	2515	2648	1308	29	0	

MEAN Hm0(M) = 1.7 LARGEST Hm0(M)= 4.2 MEAN TP(SEC)= 10.6 NO. OF CASES= 1858.

BUOY STATION 52009 13.20 N 144.50 AZIMUTH(DEGREES) = 45.0
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	<6.9	6.9- 8.0	8.1- 8.7	8.8- 9.5	9.6- 10.5	10.6- 11.7	11.8- 13.3	13.4- 15.3	15.4- 18.1	18.2- LONGER	
0.0-0.9	88	384	422	658	251	222	88	.	.	.	2113
1.0-1.9	806	1354	1414	2161	2805	1347	525	229	22	.	10663
2.0-2.9	273	1110	1110	1340	1828	1029	592	125	.	7	7414
3.0-3.9	14	118	236	229	192	66	37	.	.	.	892
4.0-4.9	.	7	.	7	.	.	.	.	.	.	14
5.0-5.9	.	.	.	.	7	7	.	.	.	.	14
6.0-6.9	.	.	.	.	.	.	.	.	.	.	0
7.0-7.9	.	.	.	.	.	.	.	.	.	.	0
8.0-8.9	.	.	.	.	.	.	.	.	.	.	0
9.0-9.9	.	.	.	.	.	.	.	.	.	.	0
10.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	1181	2973	3182	4395	5083	2671	1242	354	22	7	

MEAN Hm0(M) = 1.8 LARGEST Hm0(M)= 5.5 MEAN TP(SEC)= 9.4 NO. OF CASES= 2854.

BUOY STATION 52009 13.20 N 144.50 AZIMUTH(DEGREES) = 67.5
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	<6.9	6.9- 8.0	8.1- 8.7	8.8- 9.5	9.6- 10.5	10.6- 11.7	11.8- 13.3	13.4- 15.3	15.4- 18.1	18.2- LONGER	
0.0-0.9	281	629	636	429	251	103	14	.	7	.	2350
1.0-1.9	1887	4849	3983	3464	2576	918	185	88	88	.	18038
2.0-2.9	281	1554	1932	3161	2917	1140	362	66	.	.	11413
3.0-3.9	7	51	88	170	325	96	14	14	.	.	765
4.0-4.9	.	.	7	.	7	.	.	.	.	.	14
5.0-5.9	.	.	.	.	.	.	.	.	.	.	0
6.0-6.9	.	.	.	.	.	.	.	.	.	.	0
7.0-7.9	.	.	.	.	.	.	.	.	.	.	0
8.0-8.9	.	.	.	.	.	.	.	.	.	.	0
9.0-9.9	.	.	.	.	.	.	.	.	.	.	0
10.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	2456	7083	6646	7224	6076	2257	575	168	95	0	

MEAN Hm0(M) = 1.8 LARGEST Hm0(M)= 4.3 MEAN TP(SEC)= 8.8 NO. OF CASES= 4403.

BUOY STATION 52009 13.20 N 144.50 AZIMUTH(DEGREES) = 90.0
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	<6.9	6.9- 8.0	8.1- 8.7	8.8- 9.5	9.6- 10.5	10.6- 11.7	11.8- 13.3	13.4- 15.3	15.4- 18.1	18.2- LONGER	
0.0-0.9	155	177	81	37	81	.	.	.	.	.	531
1.0-1.9	836	1480	873	666	199	14	.	7	.	.	4075
2.0-2.9	7	125	266	399	155	51	59	7	.	.	1069
3.0-3.9	.	.	7	22	29	29	7	.	.	.	94
4.0-4.9	.	.	14	.	.	.	7	.	.	.	21
5.0-5.9	.	.	.	.	.	.	7	.	.	.	7
6.0-6.9	.	.	.	.	.	.	7	.	.	.	7
7.0-7.9	.	.	.	.	.	.	.	.	.	.	0
8.0-8.9	.	.	.	.	.	.	.	.	.	.	0
9.0-9.9	.	.	.	.	.	.	.	.	.	.	0
10.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	998	1782	1241	1124	464	94	87	14	0	0	

MEAN Hm0(M) = 1.6 LARGEST Hm0(M)= 6.1 MEAN TP(SEC)= 8.1 NO. OF CASES= 786.

BUOY STATION 52009 13.20 N 144.50 AZIMUTH(DEGREES) =112.5
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	<6.9	6.9- 8.0	8.1- 8.7	8.8- 9.5	9.6- 10.5	10.6- 11.7	11.8- 13.3	13.4- 15.3	15.4- 18.1	18.2- LONGER	
0.0-0.9	7	7	.	29	29	.	.	.	.	.	72
1.0-1.9	88	118	29	44	29	.	.	14	.	.	322
2.0-2.9	.	51	44	51	14	44	44	14	.	.	262
3.0-3.9	.	.	.	.	.	22	7	37	.	.	66
4.0-4.9	.	.	.	.	.	.	.	37	.	.	37
5.0-5.9	.	.	.	.	.	.	7	37	.	.	44
6.0-6.9	.	.	.	.	.	.	14	7	.	.	21
7.0-7.9	.	.	.	.	.	.	.	7	.	.	7
8.0-8.9	.	.	.	.	.	.	.	7	.	.	7
9.0-9.9	.	.	.	.	.	.	.	7	.	.	7
10.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	95	176	73	124	72	66	72	167	0	0	

MEAN Hm0(M) = 2.4 LARGEST Hm0(M)= 9.8 MEAN TP(SEC)= 9.9 NO. OF CASES= 116.

BUOY STATION 52009 13.20 N 144.50 AZIMUTH(DEGREES) =135.0

PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT (METRES)	<6.9	6.9-8.0	8.1-8.7	8.8-9.5	9.6-10.5	10.6-11.7	11.8-13.3	13.4-15.3	15.4-18.1	18.2-LONGER	TOTAL
0.0-0.9	.	7	.	14	14	.	.	.	.	.	35
1.0-1.9	14	37	22	7	.	.	.	7	.	.	87
2.0-2.9	.	51	14	.	.	7	.	.	.	.	72
3.0-3.9	.	14	29	.	14	14	.	.	.	.	71
4.0-4.9	.	.	.	.	.	.	.	.	.	.	0
5.0-5.9	.	.	.	.	.	.	.	.	.	.	0
6.0-6.9	.	.	.	.	.	.	.	.	.	.	0
7.0-7.9	.	.	.	.	.	.	.	.	.	.	0
8.0-8.9	.	.	.	.	.	.	.	.	.	.	0
9.0-9.9	.	.	.	.	.	.	.	.	.	.	0
10.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	14	109	65	21	28	21	0	7	0	0	

PEAK PERIOD (SECONDS)

MEAN Hm0(M) = 2.1 LARGEST Hm0(M)= 3.7 MEAN TP(SEC)= 8.5 NO. OF CASES= 37.

BUOY STATION 52009 13.20 N 144.50 AZIMUTH(DEGREES) =157.5

PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT (METRES)	<6.9	6.9-8.0	8.1-8.7	8.8-9.5	9.6-10.5	10.6-11.7	11.8-13.3	13.4-15.3	15.4-18.1	18.2-LONGER	TOTAL
0.0-0.9	.	.	.	.	.	.	.	.	.	.	0
1.0-1.9	.	51	29	7	14	.	.	.	.	.	101
2.0-2.9	.	22	51	14	7	.	7	.	.	.	101
3.0-3.9	.	.	14	.	.	7	.	.	.	.	21
4.0-4.9	.	.	.	.	.	.	.	.	.	.	0
5.0-5.9	.	.	.	.	.	.	.	.	.	.	0
6.0-6.9	.	.	.	.	.	.	.	.	.	.	0
7.0-7.9	.	.	.	.	.	.	.	.	.	.	0
8.0-8.9	.	.	.	.	.	.	.	.	.	.	0
9.0-9.9	.	.	.	.	.	.	.	.	.	.	0
10.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	0	73	94	21	21	7	7	0	0	0	

PEAK PERIOD (SECONDS)

MEAN Hm0(M) = 2.0 LARGEST Hm0(M)= 3.3 MEAN TP(SEC)= 8.5 NO. OF CASES= 31.

BUOY STATION 52009 13.20 N 144.50 AZIMUTH(DEGREES) =180.0
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	<6.9	6.9- 8.0	8.1- 8.7	8.8- 9.5	9.6- 10.5	10.6- 11.7	11.8- 13.3	13.4- 15.3	15.4- 18.1	18.2- LONGER	
0.0-0.9	7	7	.	7	.	.	.	.	.	.	21
1.0-1.9	44	59	29	14	22	.	.	.	.	.	168
2.0-2.9	7	22	29	.	22	.	.	.	.	.	80
3.0-3.9	.	.	.	.	22	51	22	.	.	.	95
4.0-4.9	.	.	.	.	.	14	29	.	.	.	43
5.0-5.9	.	.	.	.	.	.	.	.	.	.	0
6.0-6.9	.	.	.	.	.	.	.	.	.	.	0
7.0-7.9	.	.	.	.	.	.	.	.	.	.	0
8.0-8.9	.	.	.	.	.	.	.	.	.	.	0
9.0-9.9	.	.	.	.	.	.	.	.	.	.	0
10.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	58	88	58	21	66	65	51	0	0	0	

MEAN Hm0(M) = 2.3 LARGEST Hm0(M) = 4.5 MEAN TP(SEC) = 9.0 NO. OF CASES= 56.

BUOY STATION 52009 13.20 N 144.50 AZIMUTH(DEGREES) =202.5
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	<6.9	6.9- 8.0	8.1- 8.7	8.8- 9.5	9.6- 10.5	10.6- 11.7	11.8- 13.3	13.4- 15.3	15.4- 18.1	18.2- LONGER	
0.0-0.9	14	7	7	.	7	.	.	.	.	.	35
1.0-1.9	199	125	59	66	66	14	.	.	.	.	529
2.0-2.9	.	59	51	14	.	51	.	.	.	.	175
3.0-3.9	.	.	.	7	.	29	51	7	.	.	94
4.0-4.9	.	.	.	.	7	7	7	.	.	.	21
5.0-5.9	.	.	.	.	.	.	.	.	.	.	0
6.0-6.9	.	.	.	.	.	.	.	.	.	.	0
7.0-7.9	.	.	.	.	.	.	.	.	.	.	0
8.0-8.9	.	.	.	.	.	.	.	.	.	.	0
9.0-9.9	.	.	.	.	.	.	.	.	.	.	0
10.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	213	191	117	87	80	101	58	7	0	0	

MEAN Hm0(M) = 1.9 LARGEST Hm0(M) = 4.4 MEAN TP(SEC) = 8.3 NO. OF CASES= 117.

BUOY STATION 52009 13.20 N 144.50 AZIMUTH(DEGREES) =225.0
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	<6.9	6.9- 8.0	8.1- 8.7	8.8- 9.5	9.6- 10.5	10.6- 11.7	11.8- 13.3	13.4- 15.3	15.4- 18.1	18.2- LONGER	
0.0-0.9	14	7	.	.	.	.	.	.	.	.	21
1.0-1.9	207	340	340	44	140	7	.	.	.	.	1078
2.0-2.9	7	22	96	14	.	22	14	.	.	.	175
3.0-3.9	.	14	7	.	.	14	81	7	.	.	123
4.0-4.9	.	.	.	.	.	.	14	.	.	.	14
5.0-5.9	.	.	.	.	.	7	7	.	.	.	14
6.0-6.9	.	.	.	.	.	.	.	.	.	.	0
7.0-7.9	.	.	.	.	.	.	.	.	.	.	0
8.0-8.9	.	.	.	.	.	.	.	.	.	.	0
9.0-9.9	.	.	.	.	.	.	.	.	.	.	0
10.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	228	383	443	58	140	50	116	7	0	0	

MEAN Hm0(M) = 1.8 LARGEST Hm0(M)= 5.9 MEAN TP(SEC)= 8.4 NO. OF CASES= 194.

BUOY STATION 52009 13.20 N 144.50 AZIMUTH(DEGREES) =247.5
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	<6.9	6.9- 8.0	8.1- 8.7	8.8- 9.5	9.6- 10.5	10.6- 11.7	11.8- 13.3	13.4- 15.3	15.4- 18.1	18.2- LONGER	
0.0-0.9	37	51	51	14	.	.	.	.	.	.	153
1.0-1.9	103	236	207	199	44	44	.	.	.	.	833
2.0-2.9	.	14	44	103	7	81	111	37	.	.	397
3.0-3.9	.	.	7	51	.	22	133	44	.	.	257
4.0-4.9	.	.	.	.	.	29	14	.	.	.	43
5.0-5.9	.	.	.	.	.	.	.	.	.	.	0
6.0-6.9	.	.	.	.	.	.	.	.	.	.	0
7.0-7.9	.	.	.	.	.	.	.	.	.	.	0
8.0-8.9	.	.	.	.	.	.	.	.	.	.	0
9.0-9.9	.	.	.	.	.	.	.	.	.	.	0
10.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	140	301	309	367	51	176	258	81	0	0	

MEAN Hm0(M) = 1.9 LARGEST Hm0(M)= 4.9 MEAN TP(SEC)= 9.4 NO. OF CASES= 229.

BUOY STATION 52009 13.20 N 144.50 AZIMUTH(DEGREES) =270.0
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	<6.9	6.9-8.0	8.1-8.7	8.8-9.5	9.6-10.5	10.6-11.7	11.8-13.3	13.4-15.3	15.4-18.1	18.2-LONGER	
0.0-0.9	.	14	14	7	14	.	.	.	.	.	49
1.0-1.9	37	66	155	140	103	96	96	.	.	.	693
2.0-2.9	.	7	7	66	44	273	118	29	.	.	544
3.0-3.9	.	.	7	.	.	22	66	59	7	.	161
4.0-4.9	.	.	.	.	.	22	.	.	.	.	22
5.0-5.9	.	.	.	.	.	.	.	.	.	.	0
6.0-6.9	.	.	.	.	.	.	.	.	.	.	0
7.0-7.9	.	.	.	.	.	.	.	.	.	.	0
8.0-8.9	.	.	.	.	.	.	.	.	.	.	0
9.0-9.9	.	.	.	.	.	.	.	.	.	.	0
10.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	37	87	183	213	161	413	280	88	7	0	

MEAN Hm0(M) = 2.1 LARGEST Hm0(M)= 4.4 MEAN TP(SEC)= 10.5 NO. OF CASES= 200.

BUOY STATION 52009 13.20 N 144.50 AZIMUTH(DEGREES) =292.5
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	<6.9	6.9-8.0	8.1-8.7	8.8-9.5	9.6-10.5	10.6-11.7	11.8-13.3	13.4-15.3	15.4-18.1	18.2-LONGER	
0.0-0.9	.	.	7	14	14	7	.	.	.	.	42
1.0-1.9	14	14	96	103	236	192	192	7	.	.	854
2.0-2.9	.	.	.	44	103	148	133	29	.	.	457
3.0-3.9	.	.	.	.	.	7	14	29	.	.	50
4.0-4.9	.	.	.	.	.	7	.	.	.	.	7
5.0-5.9	.	.	.	.	.	.	.	.	.	.	0
6.0-6.9	.	.	.	.	.	.	.	.	.	.	0
7.0-7.9	.	.	.	.	.	.	.	.	.	.	0
8.0-8.9	.	.	.	.	.	.	.	.	.	.	0
9.0-9.9	.	.	.	.	.	.	.	.	.	.	0
10.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	14	14	103	161	353	361	339	65	0	0	

MEAN Hm0(M) = 1.8 LARGEST Hm0(M)= 4.5 MEAN TP(SEC)= 10.8 NO. OF CASES= 192.

BUOY STATION 52009 13.20 N 144.50 AZIMUTH(DEGREES) =315.0
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	<6.9	6.9- 8.0	8.1- 8.7	8.8- 9.5	9.6- 10.5	10.6- 11.7	11.8- 13.3	13.4- 15.3	15.4- 18.1	18.2- LONGER	
0.0-0.9	.	7	7	29	96	59	7	.	.	.	205
1.0-1.9	7	14	37	155	266	562	318	74	.	.	1433
2.0-2.9	.	.	.	37	96	59	207	44	.	.	443
3.0-3.9	.	.	.	.	.	14	74	7	.	.	95
4.0-4.9	.	.	.	.	.	7	.	.	.	.	7
5.0-5.9	.	.	.	.	.	.	.	.	.	.	0
6.0-6.9	.	.	.	.	.	.	.	.	.	.	0
7.0-7.9	.	.	.	.	.	.	.	.	.	.	0
8.0-8.9	.	.	.	.	.	.	.	.	.	.	0
9.0-9.9	.	.	.	.	.	.	.	.	.	.	0
10.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	7	21	44	221	458	701	606	125	0	0	

MEAN Hm0(M) = 1.6 LARGEST Hm0(M) = 4.2 MEAN TP(SEC) = 11.1 NO. OF CASES= 296.

BUOY STATION 52009 13.20 N 144.50 AZIMUTH(DEGREES) =337.5
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	<6.9	6.9- 8.0	8.1- 8.7	8.8- 9.5	9.6- 10.5	10.6- 11.7	11.8- 13.3	13.4- 15.3	15.4- 18.1	18.2- LONGER	
0.0-0.9	7	14	7	103	266	74	22	.	.	.	493
1.0-1.9	7	66	125	496	688	481	333	14	.	.	2210
2.0-2.9	.	22	14	81	296	414	325	7	7	.	1166
3.0-3.9	.	.	7	7	14	125	207	.	.	.	360
4.0-4.9	.	.	.	.	.	.	.	.	.	.	0
5.0-5.9	.	.	.	.	.	.	.	.	.	.	0
6.0-6.9	.	.	.	.	.	.	.	.	.	.	0
7.0-7.9	.	.	.	.	.	.	.	.	.	.	0
8.0-8.9	.	.	.	.	.	.	.	.	.	.	0
9.0-9.9	.	.	.	.	.	.	.	.	.	.	0
10.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	14	102	153	687	1264	1094	887	21	7	0	

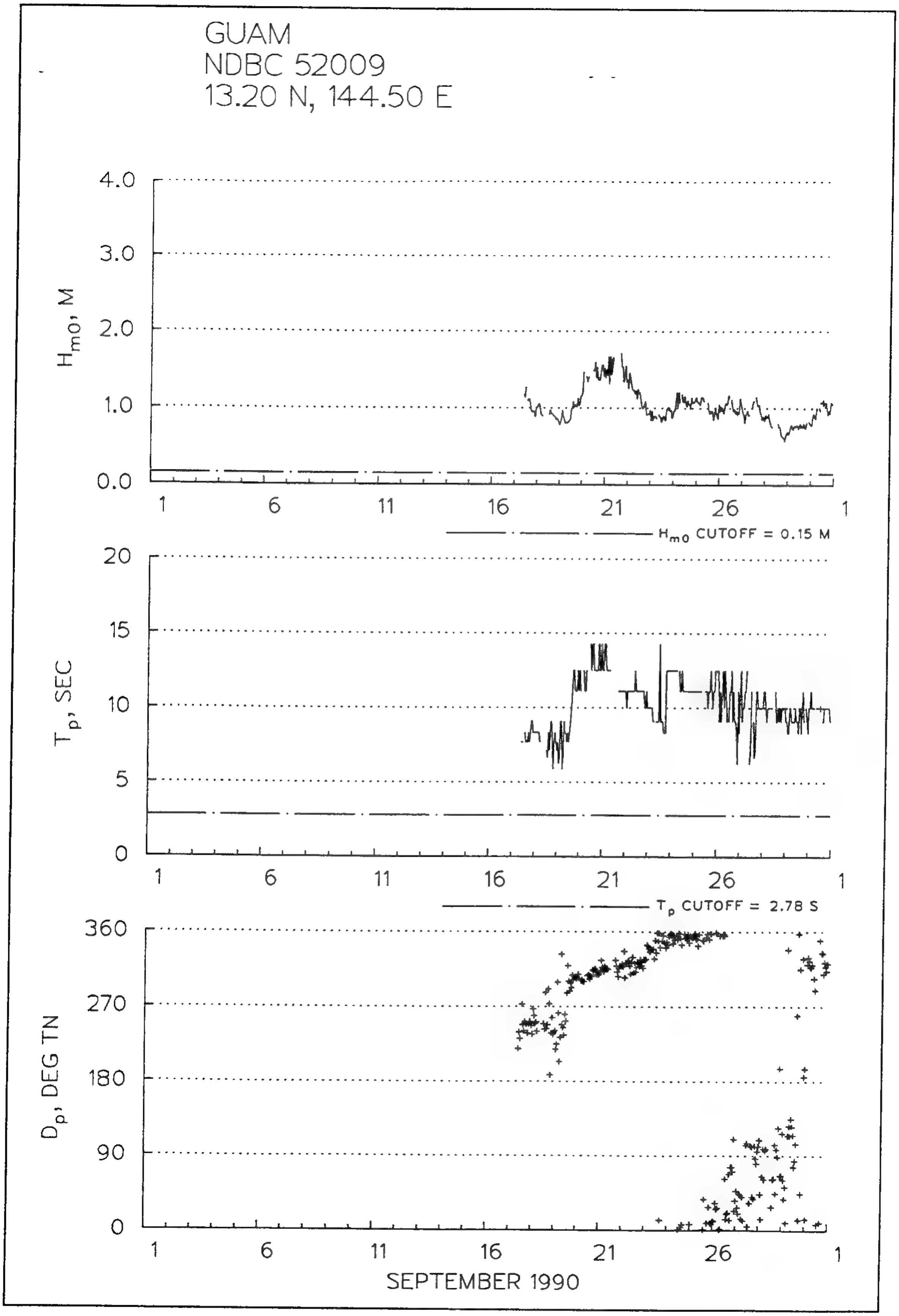
MEAN Hm0(M) = 1.8 LARGEST Hm0(M) = 3.8 MEAN TP(SEC) = 10.6 NO. OF CASES= 573.

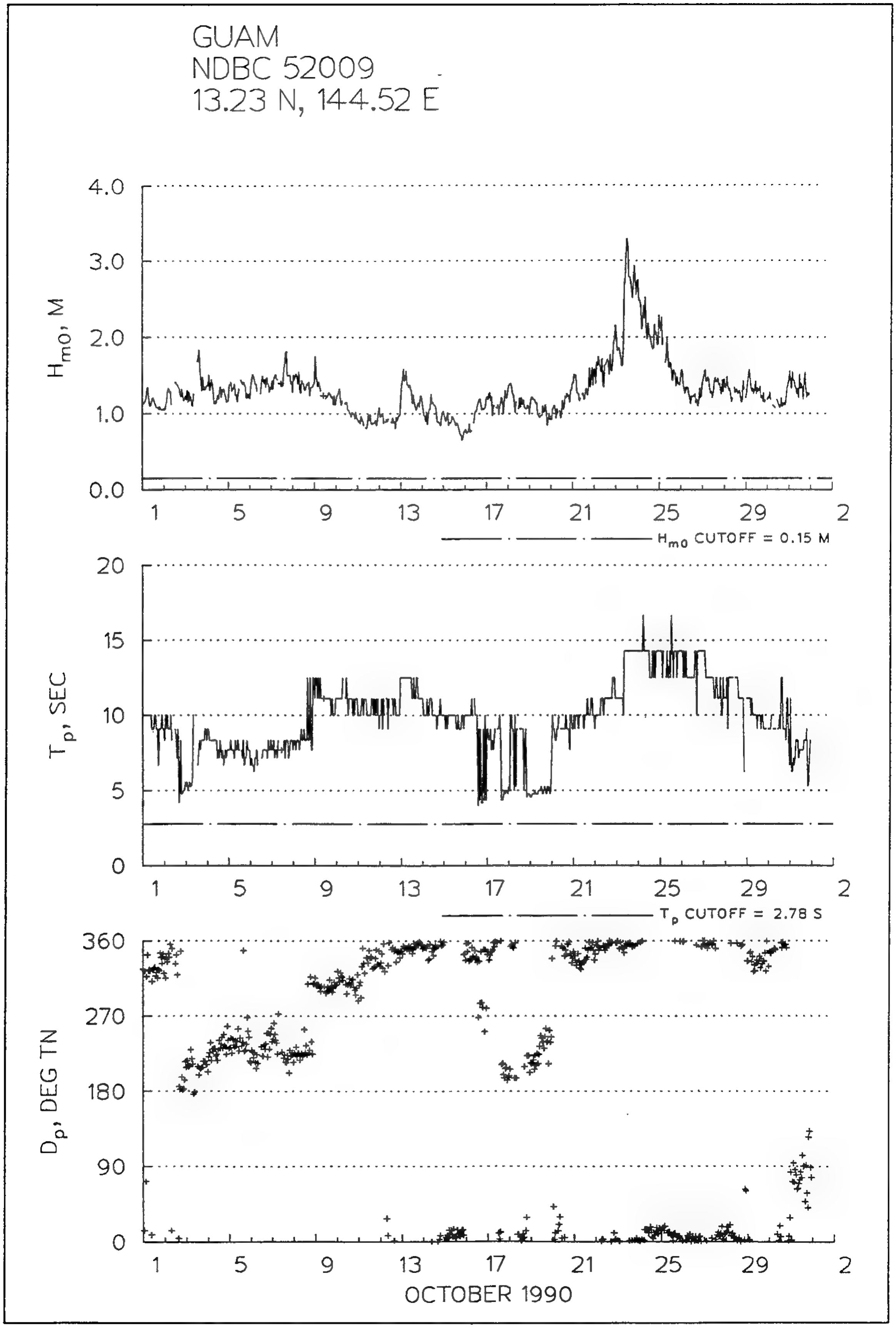
BUOY STATION 52009 13.20 N 144.50 FOR ALL DIRECTIONS
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD

HEIGHT(METRES)	<6.9	6.9-8.0	8.1-8.7	8.8-9.5	9.6-10.5	10.6-11.7	11.8-13.3	13.4-15.3	15.4-18.1	18.2-LONGER	TOTAL
0.0-0.9	636	1443	1480	1791	1517	903	281	59	7	.	8117
1.0-1.9	4471	9387	8506	10039	10276	6678	4693	1584	148	.	55782
2.0-2.9	688	3568	4197	6322	6870	5019	3339	1280	59	7	31349
3.0-3.9	37	244	473	718	755	718	918	370	59	.	4292
4.0-4.9	.	7	37	22	22	96	81	37	.	.	302
5.0-5.9	.	.	.	.	14	14	22	37	.	.	87
6.0-6.9	.	.	.	.	.	.	22	7	.	.	29
7.0-7.9	.	.	.	.	.	.	.	7	.	.	7
8.0-8.9	.	.	.	.	.	.	.	7	.	.	7
9.0-9.9	.	.	.	.	.	.	.	7	.	.	7
10.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	5832	14649	14693	18892	19454	13428	9356	3395	273	7	

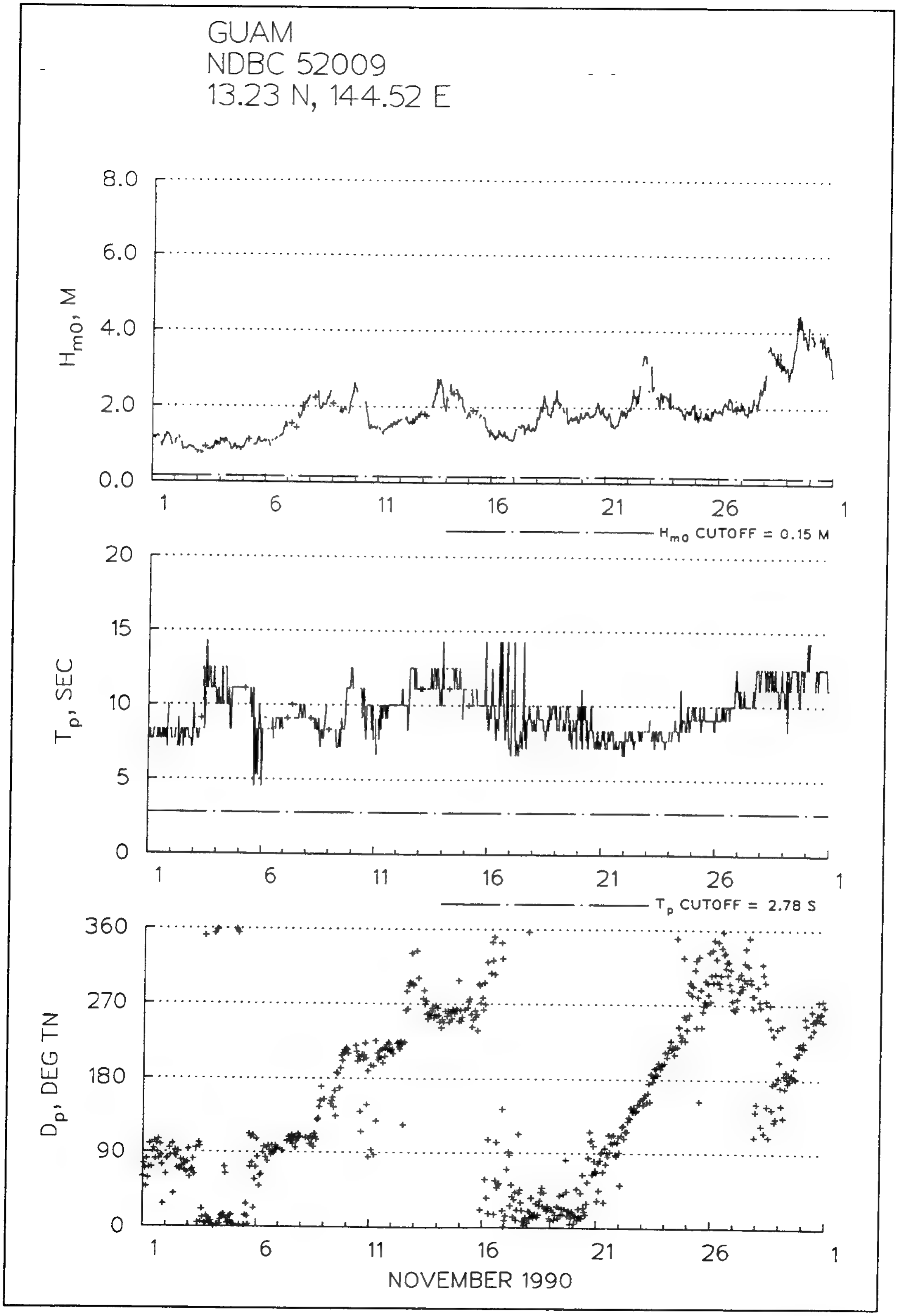
MEAN Hm0(M)= 1.8 LARGEST Hm0(M)= 9.8 MEAN TP(SEC)= 9.5 TOTAL CASES= 13507.

Appendix D
Measured Wave Data Plots

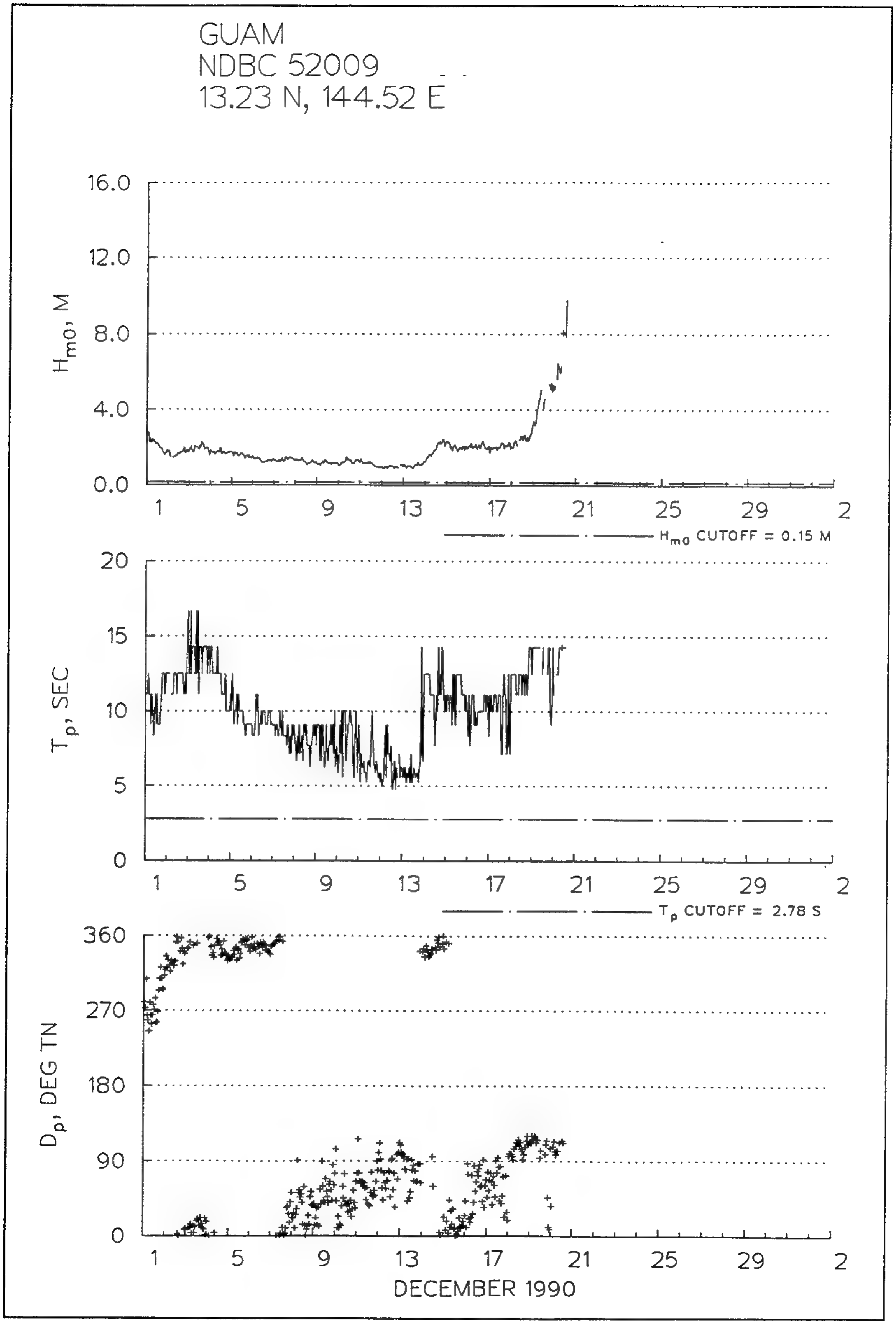

GUAM
NDBC 52009
13.20 N, 144.50 E
4.0
3.0
2.0
1.0
0.0
H_{m0}, M
1
6
11
16
21
26
1
H_{m0} CUTOFF = 0.15 M
20
15
10
5
0
T_p, SEC
T_p CUTOFF = 2.78 S
360
270
180
90
0
D_p, DEG TN
SEPTEMBER 1990

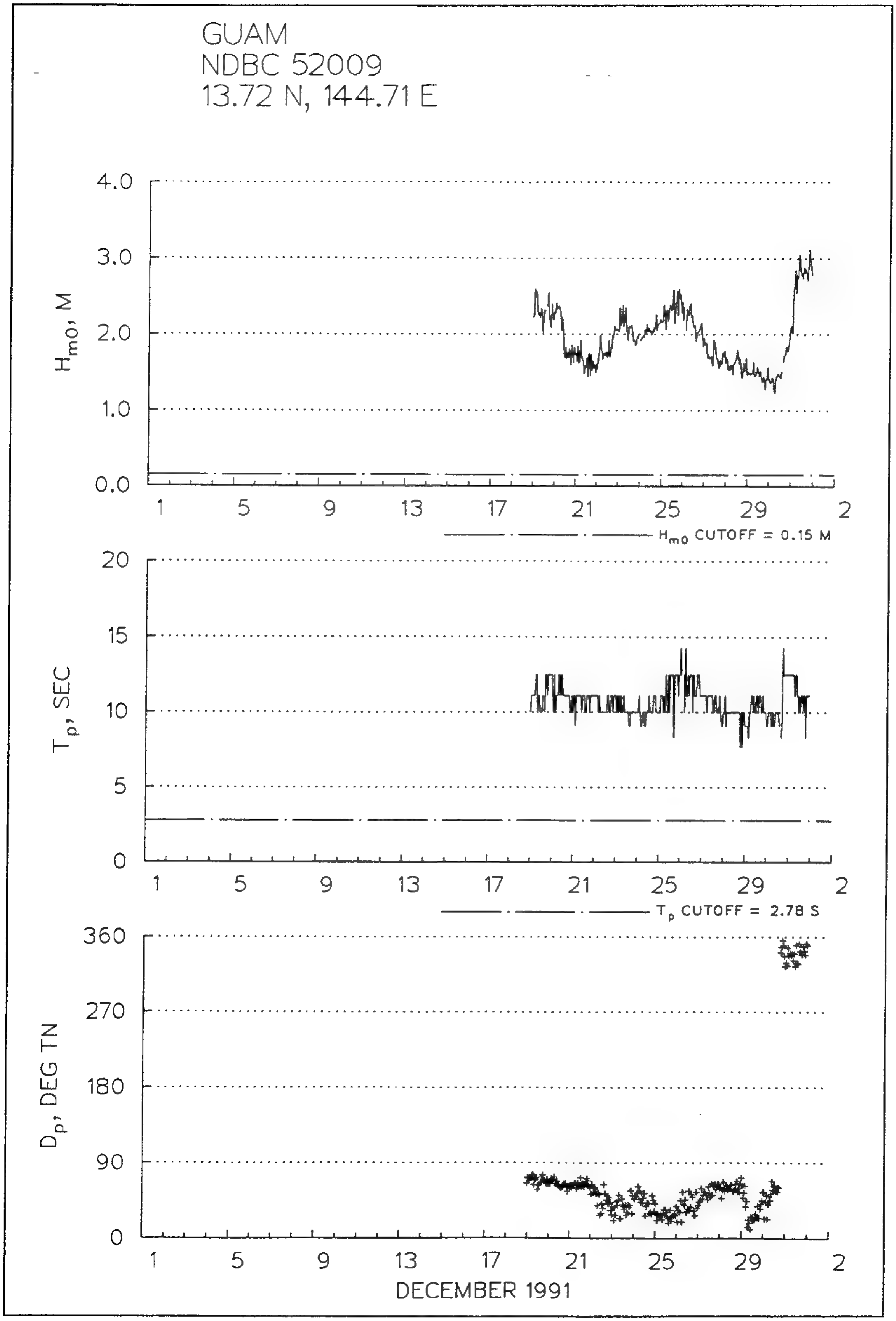


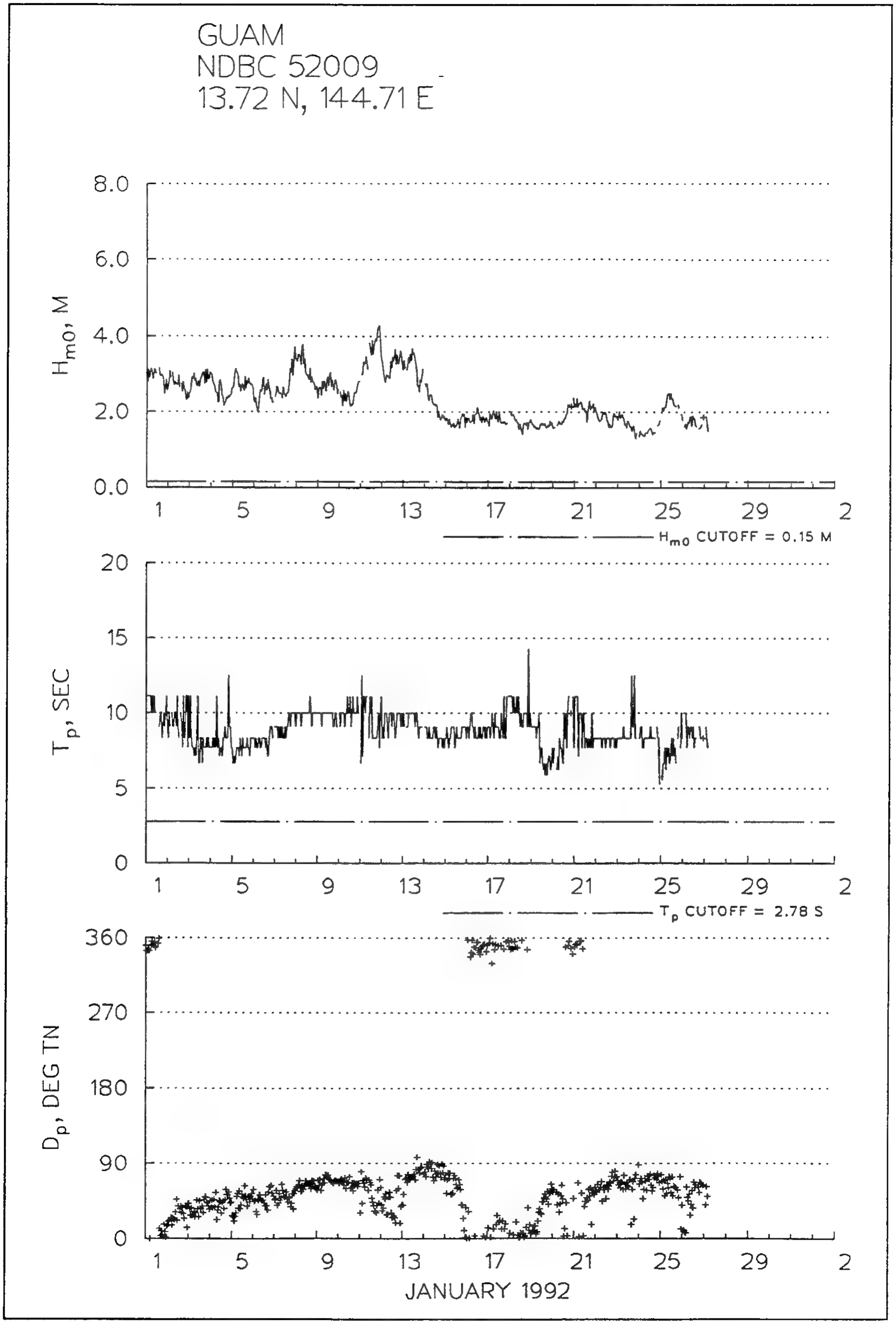
GUAM
NDBC 52009
13.23 N, 144.52 E
4.0
3.0
2.0
1.0
0.0
H_{m0}, M
1
5
9
13
17
21
25
29
2
H_{m0} CUTOFF = 0.15 M
20
15
10
5
0
T_p, SEC
T_p CUTOFF = 2.78 S
360
270
180
90
0
D_p, DEG TN
OCTOBER 1990



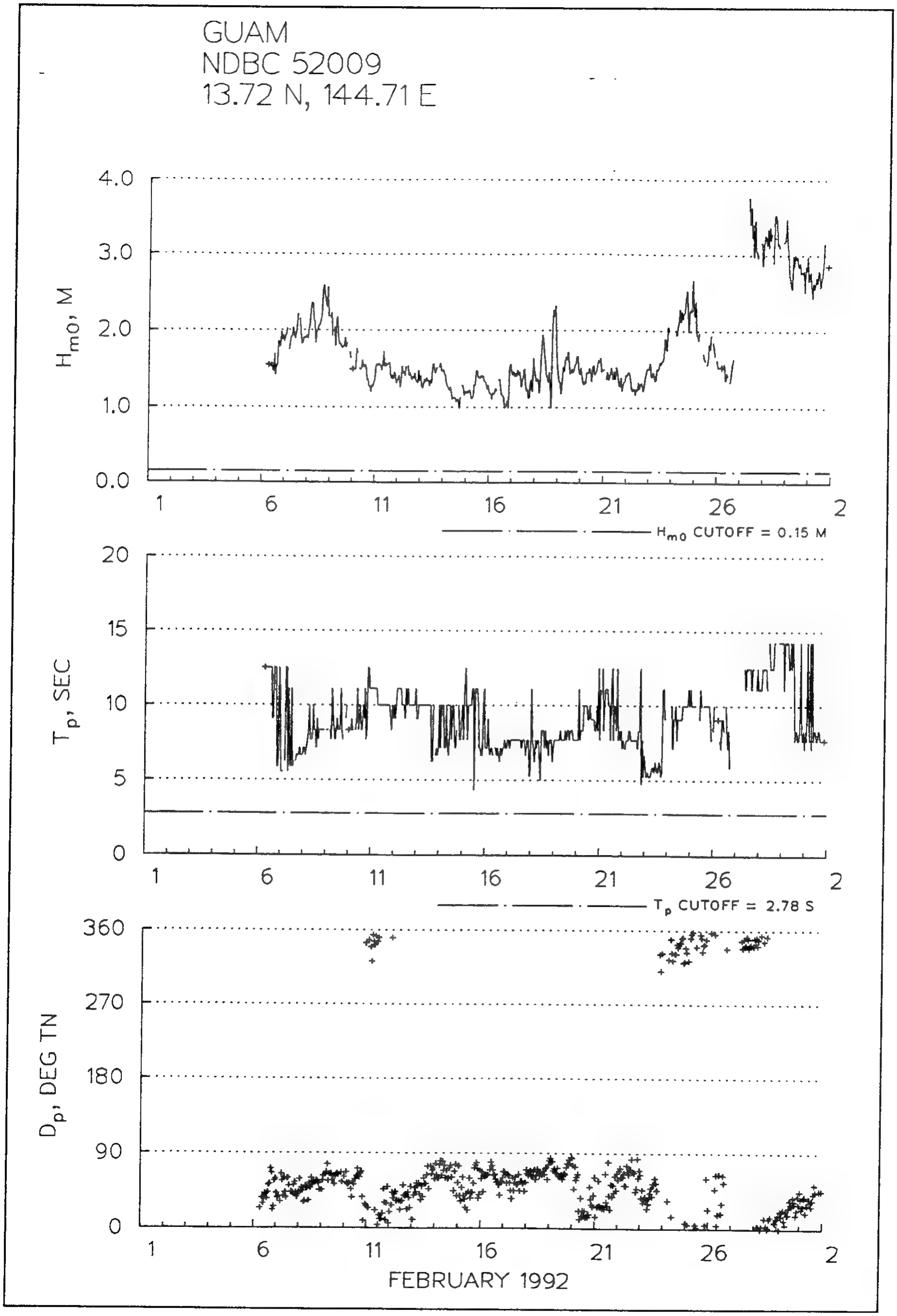
GUAM
NDBC 52009
13.23 N, 144.52 E
8.0
6.0
4.0
2.0
0.0
H_{m0}, M
1
6
11
16
21
26
1
H_{mo} CUTOFF = 0.15 M
20
15
10
5
0
T_p, SEC
T_p CUTOFF = 2.78 S
360
270
180
90
0
D_p, DEG TN
NOVEMBER 1990


GUAM
NDBC 52009
13.23 N, 144.52 E
16.0
12.0
8.0
4.0
0.0
H_{m0}, M
1
5
9
13
17
21
25
29
2
H_{m0} CUTOFF = 0.15 M
20
15
10
5
0
T_p, SEC
T_p CUTOFF = 2.78 S
360
270
180
90
0
D_p, DEG TN
DECEMBER 1990

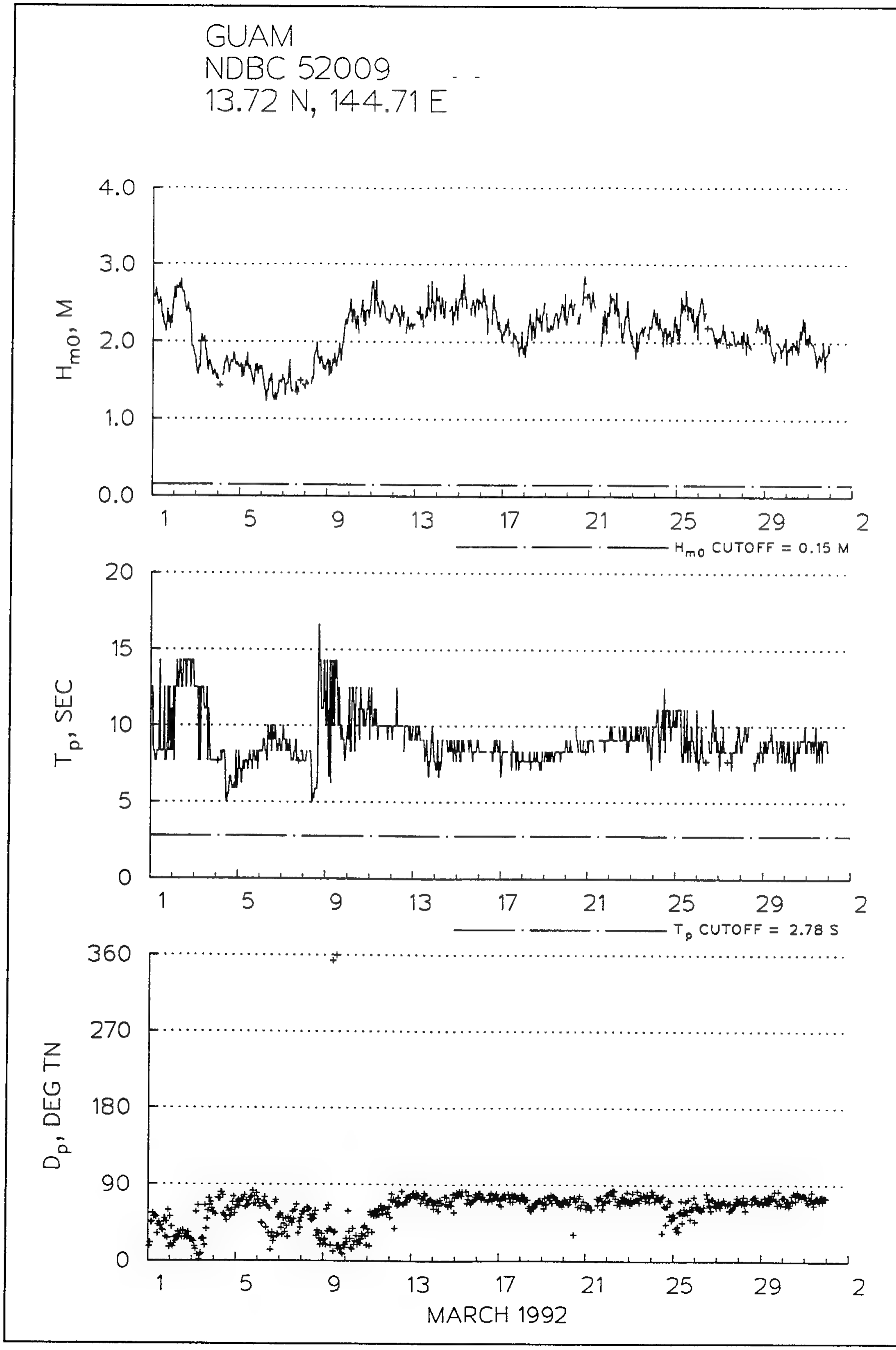

GUAM
NDBC 52009
13.72 N, 144.71 E
4.0
3.0
2.0
1.0
0.0
H_m0, M
1
5
9
13
17
21
25
29
2
H_m0 CUTOFF = 0.15 M
20
15
10
5
0
T_p, SEC
T_p CUTOFF = 2.78 S
360
270
180
90
0
D_p, DEG TN
DECEMBER 1991

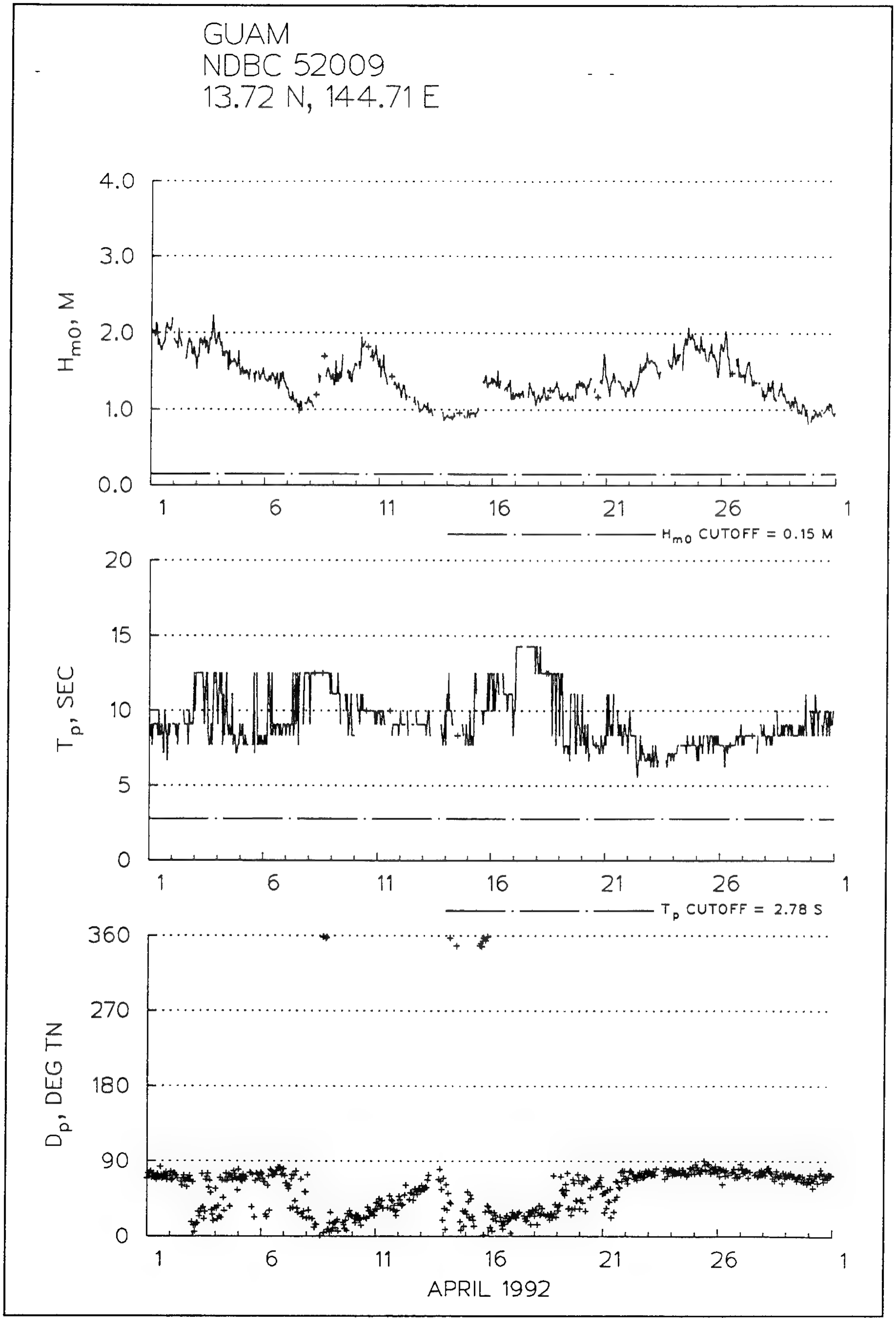


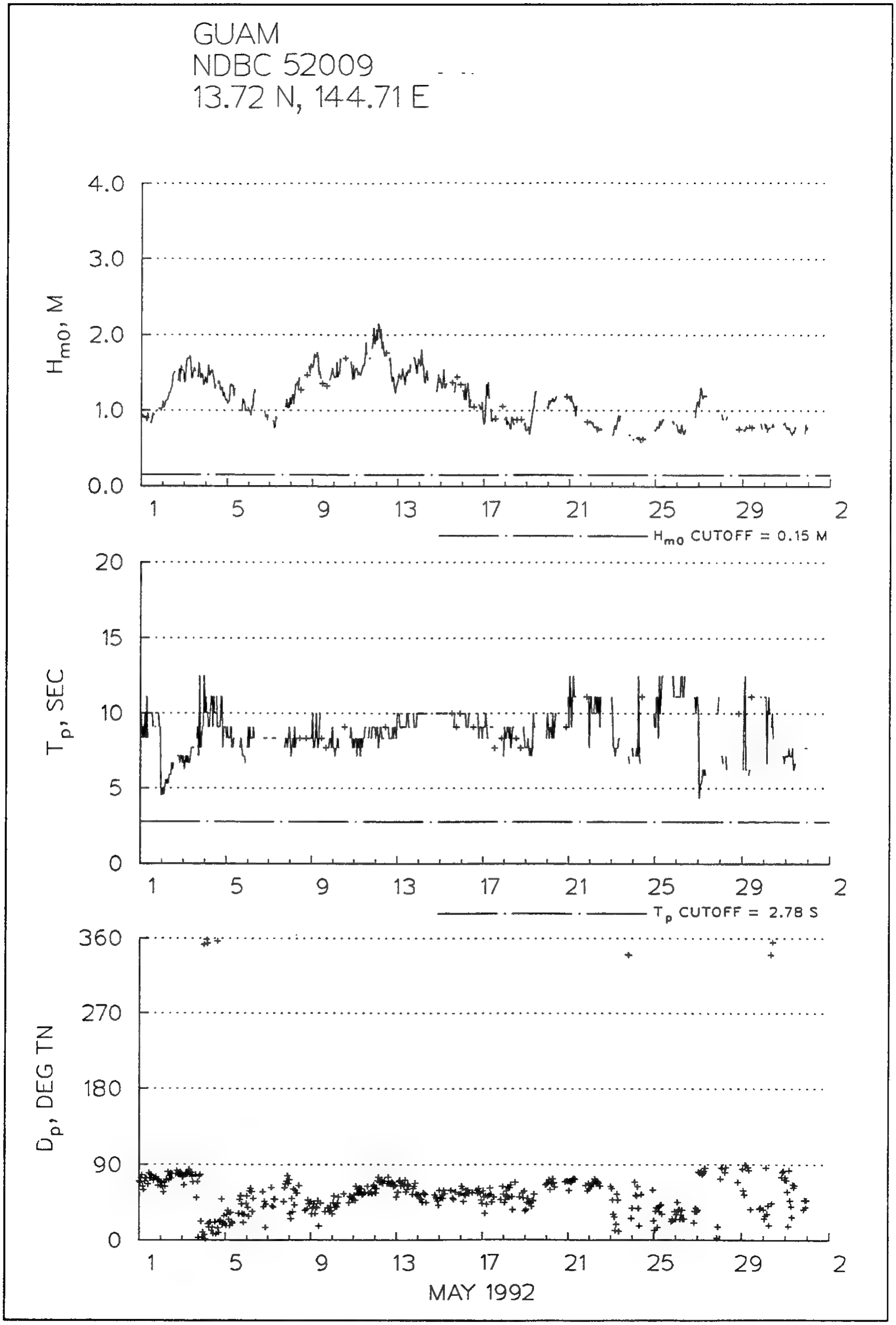
GUAM
NDBC 52009
13.72 N, 144.71 E
8.0
6.0
4.0
2.0
0.0
H_{m0}, M
1
5
9
13
17
21
25
29
2
H_{m0} CUTOFF = 0.15 M
20
15
10
5
0
T_p, SEC
T_p CUTOFF = 2.78 S
360
270
180
90
0
D_p, DEG TN
JANUARY 1992

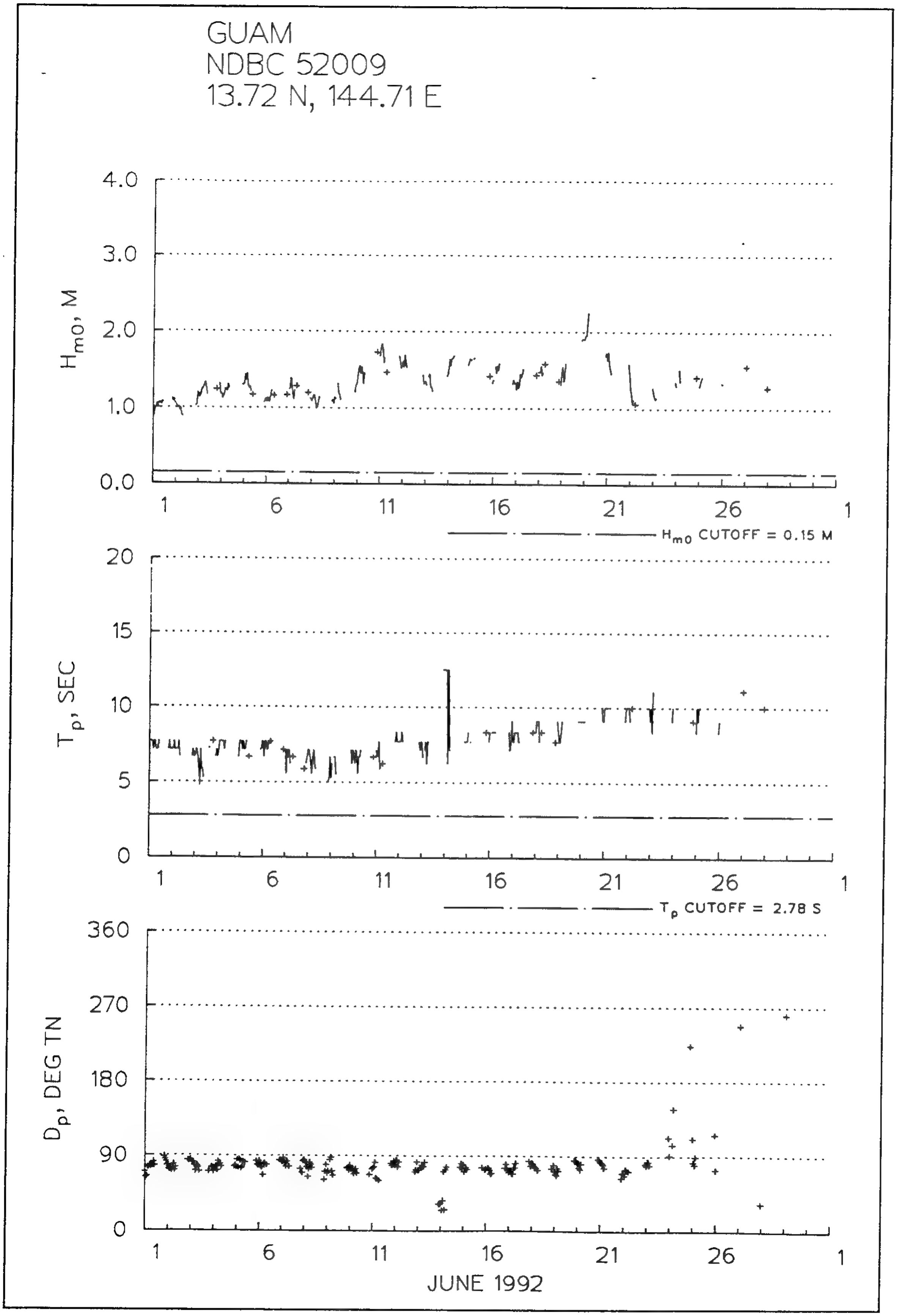


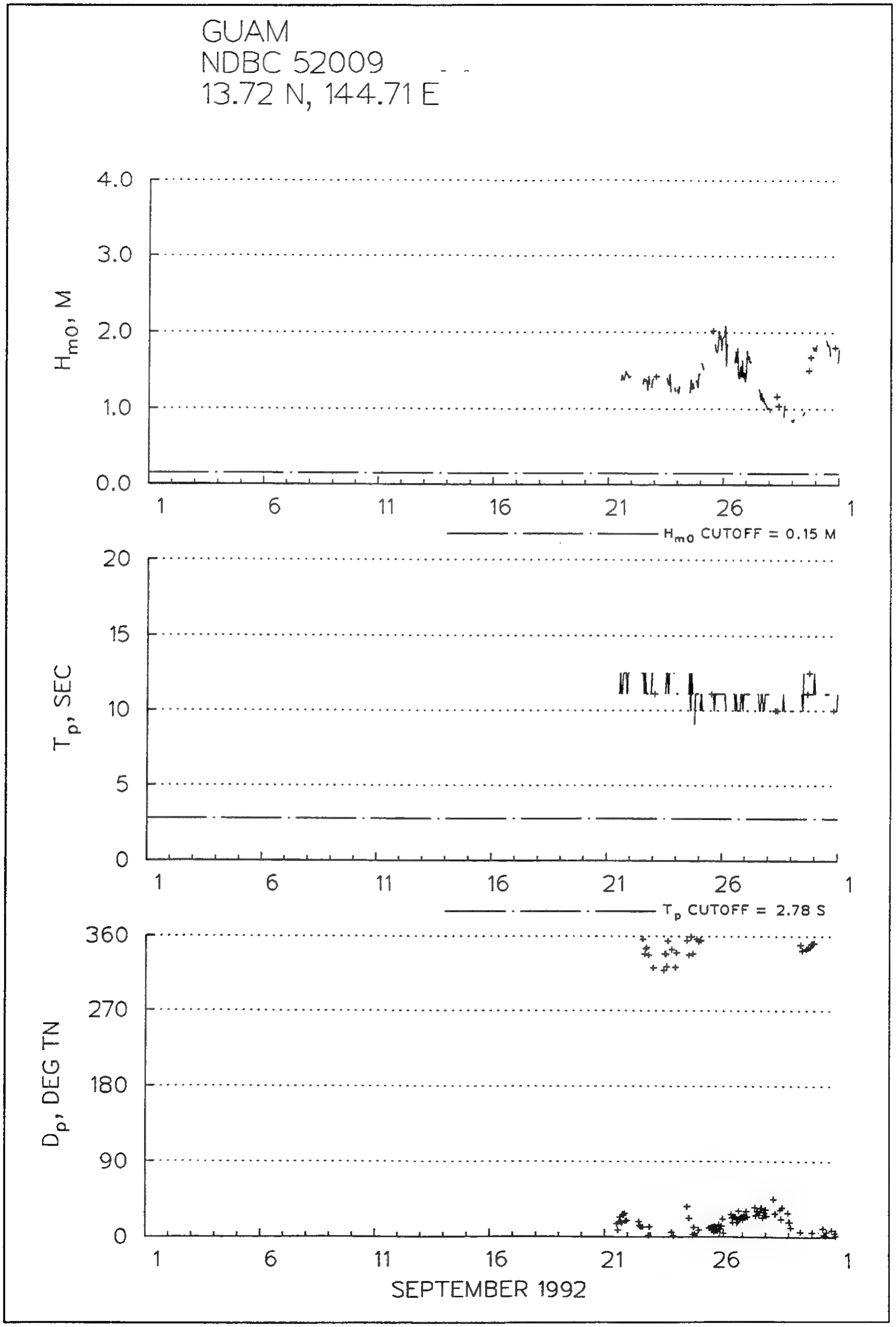
GUAM
NDBC 52009
13.72 N, 144.71 E
4.0
3.0
2.0
1.0
0.0
H_{m0}, M
1
6
11
16
21
26
2
H_{m0} CUTOFF = 0.15 M
20
15
10
5
0
T_p, SEC
T_p CUTOFF = 2.78 S
360
270
180
90
0
D_p, DEG TN
FEBRUARY 1992

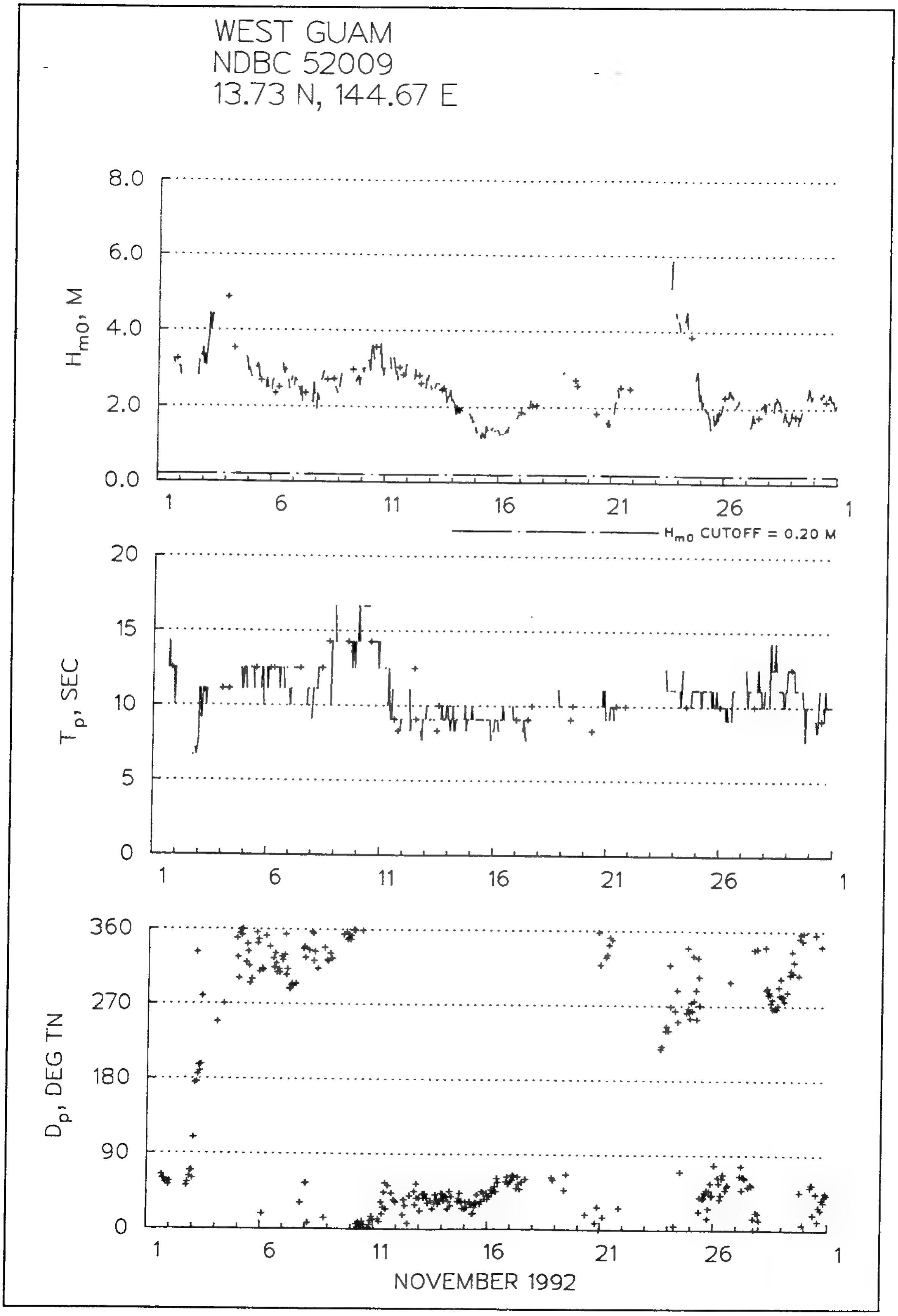

GUAM
NDBC 52009
13.72 N, 144.71 E
H_{m0}, M
4.0
3.0
2.0
1.0
0.0
1
5
9
13
17
21
25
29
2
H_{m0} CUTOFF = 0.15 M
T_p, SEC
20
15
10
5
0
T_p CUTOFF = 2.78 S
D_p, DEG TN
360
270
180
90
0
MARCH 1992

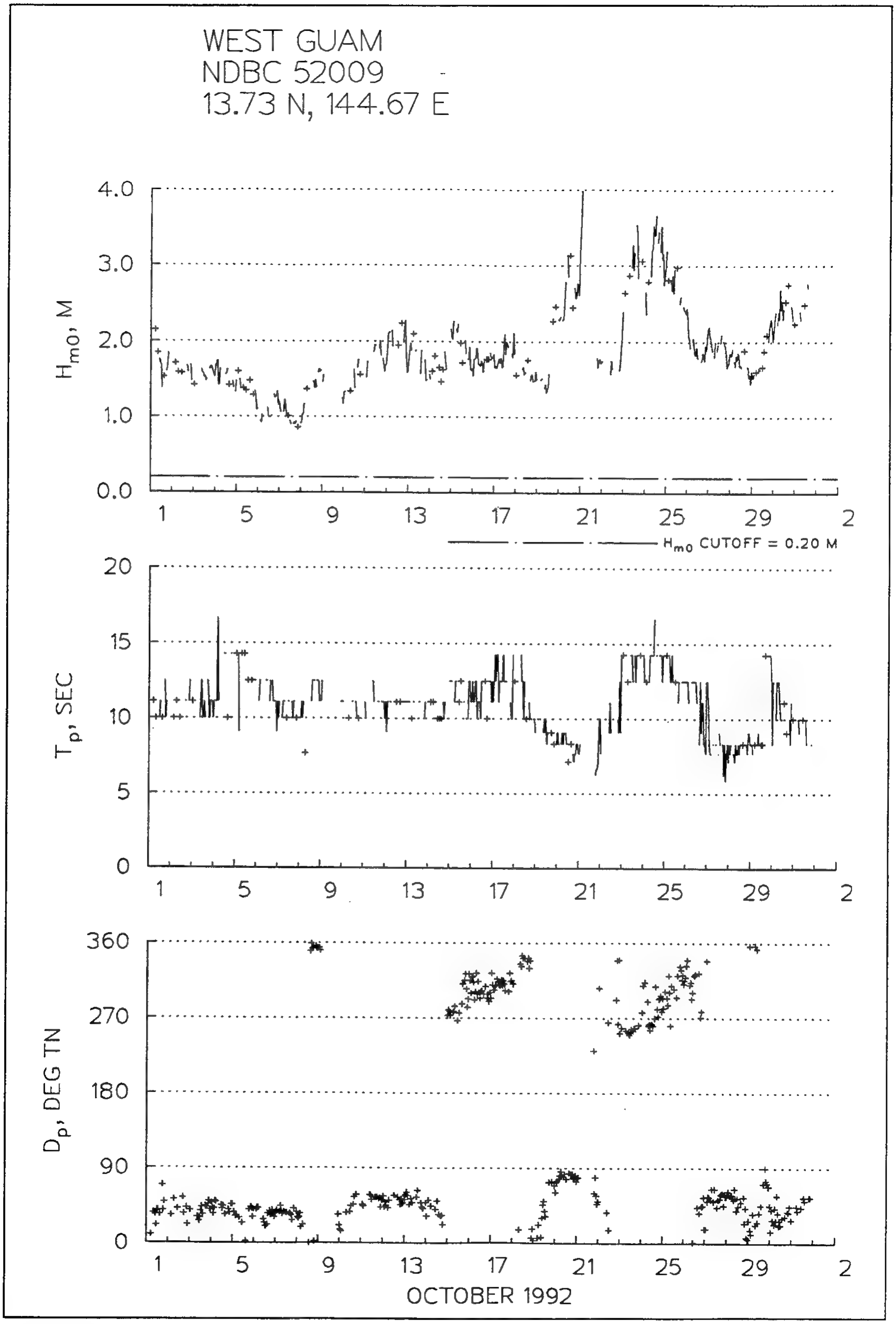

GUAM
NDBC 52009
13.72 N, 144.71 E
4.0
3.0
2.0
1.0
0.0
H_{m0}, M
1
6
11
16
21
26
1
H_{m0} CUTOFF = 0.15 M
20
15
10
5
0
T_p, SEC
1
6
11
16
21
26
1
T_p CUTOFF = 2.78 S
360
270
180
90
0
D_p, DEG TN
1
6
11
16
21
26
1
APRIL 1992

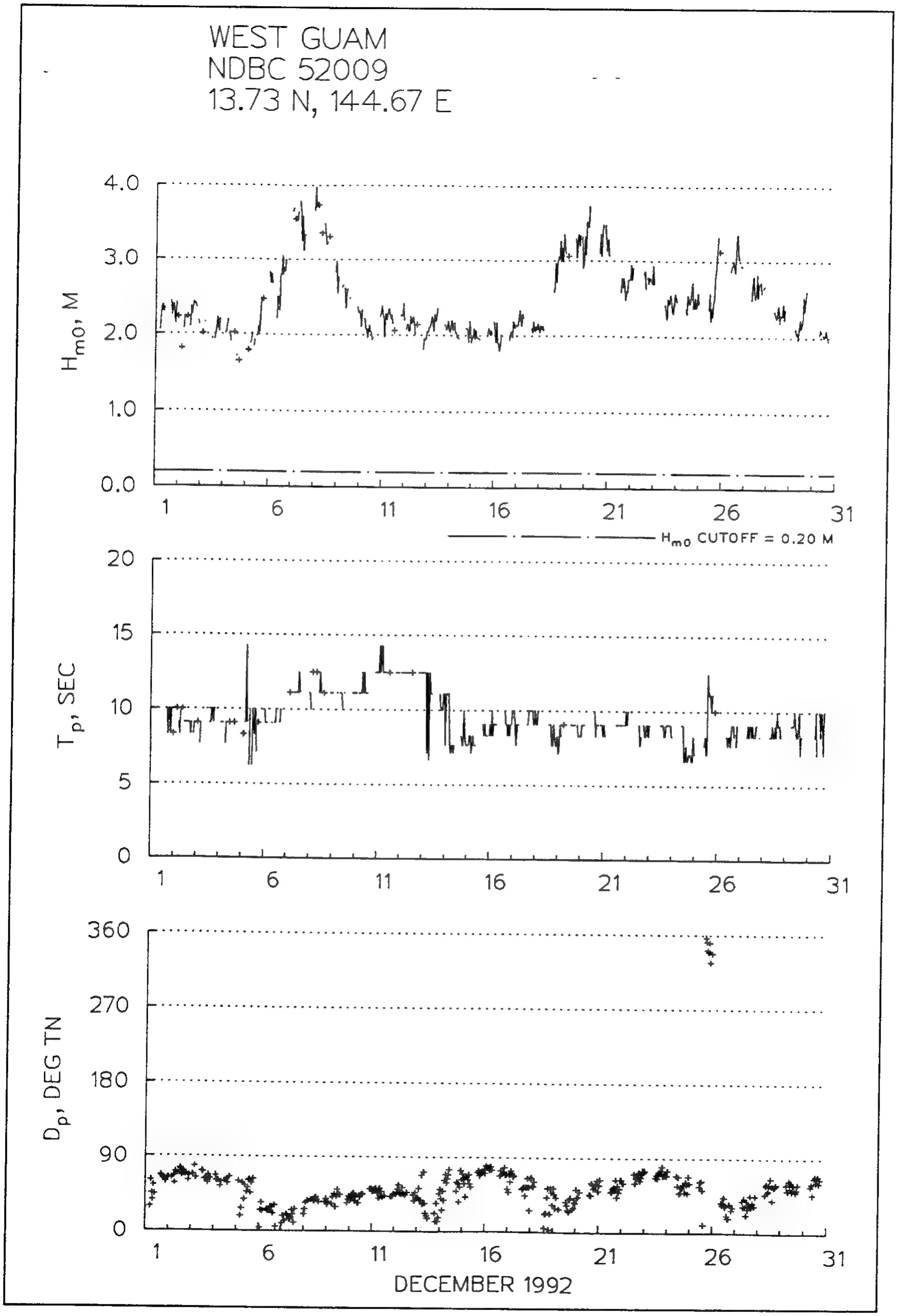

GUAM
NDBC 52009
13.72 N, 144.71 E
H_{m0}, M
4.0
3.0
2.0
1.0
0.0
1
5
9
13
17
21
25
29
2
H_{m0} CUTOFF = 0.15 M
T_p, SEC
20
15
10
5
0
T_p CUTOFF = 2.78 S
D_p, DEG TN
360
270
180
90
0
MAY 1992

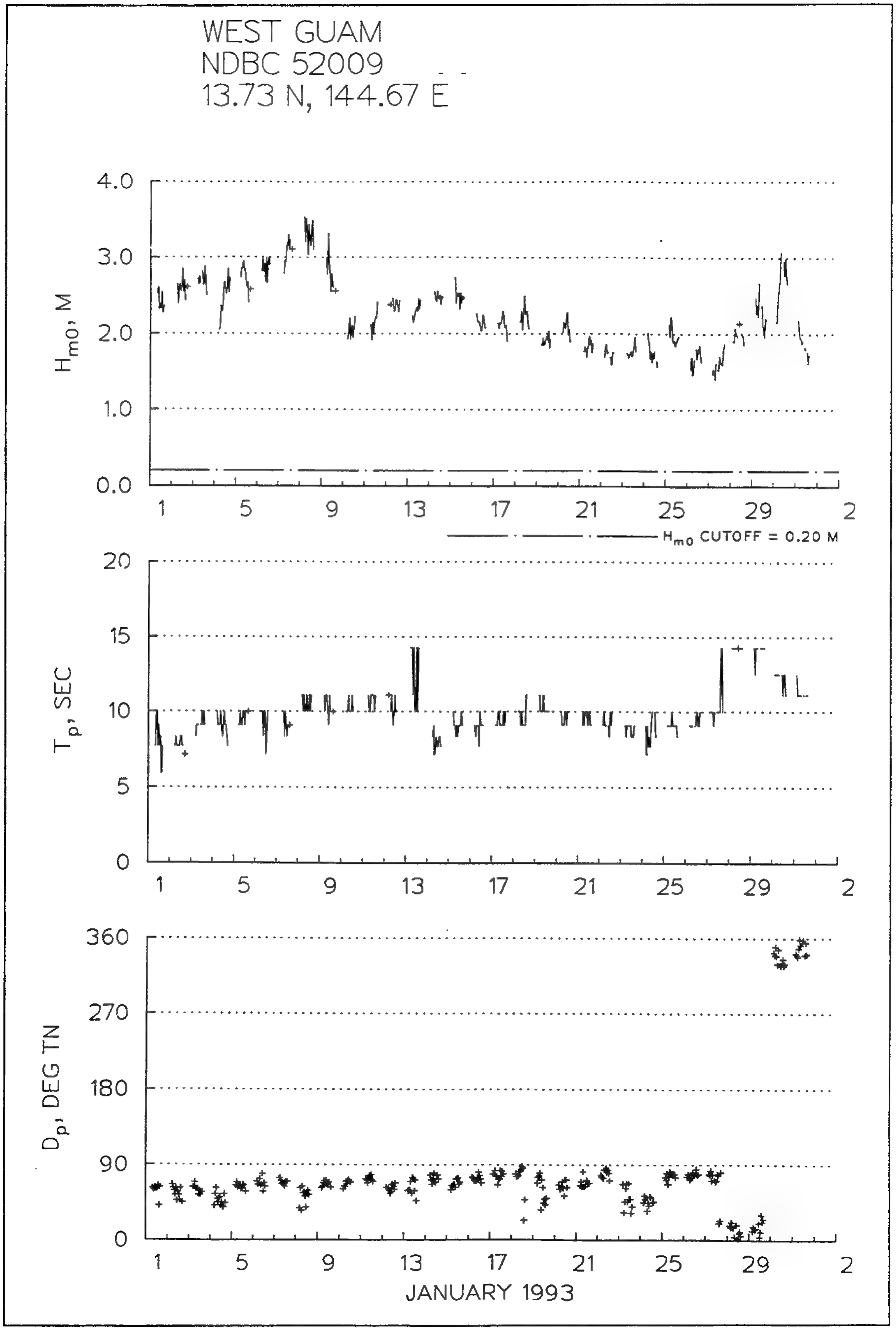

GUAM
NDBC 52009
13.72 N, 144.71 E
4.0
3.0
2.0
1.0
0.0
H_{m0}, M
1
6
11
16
21
26
1
H_{m0} CUTOFF = 0.15 M
20
15
10
5
0
T_p, SEC
T_p CUTOFF = 2.78 S
360
270
180
90
0
D_p, DEG TN
JUNE 1992

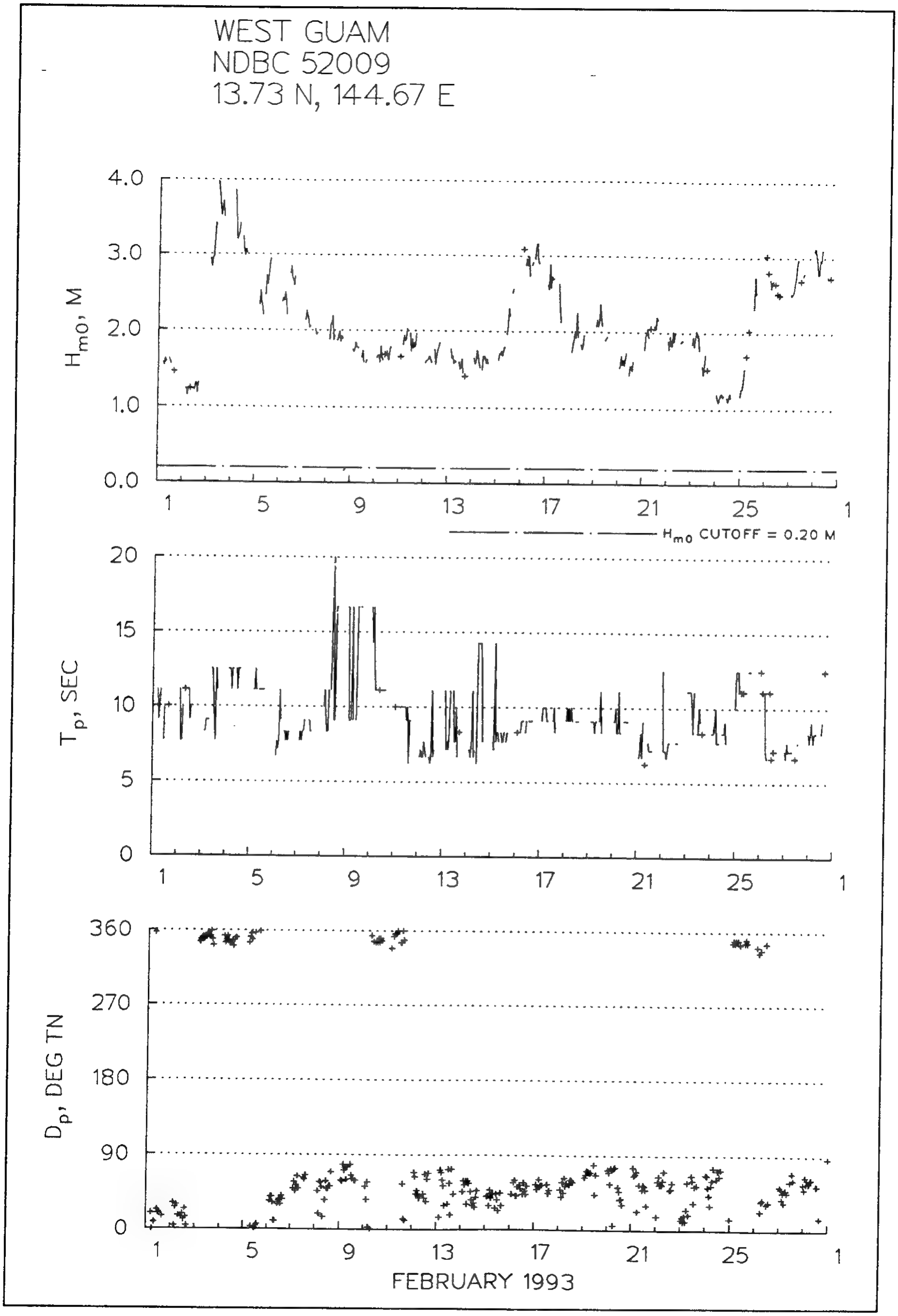

GUAM
NDBC 52009
13.72 N, 144.71 E
4.0
3.0
2.0
1.0
0.0
H_{m0}, M
1
6
11
16
21
26
1
H_{m0} CUTOFF = 0.15 M
20
15
10
5
0
T_p, SEC
1
6
11
16
21
26
1
T_p CUTOFF = 2.78 S
360
270
180
90
0
D_p, DEG TN
1
6
11
16
21
26
1
SEPTEMBER 1992

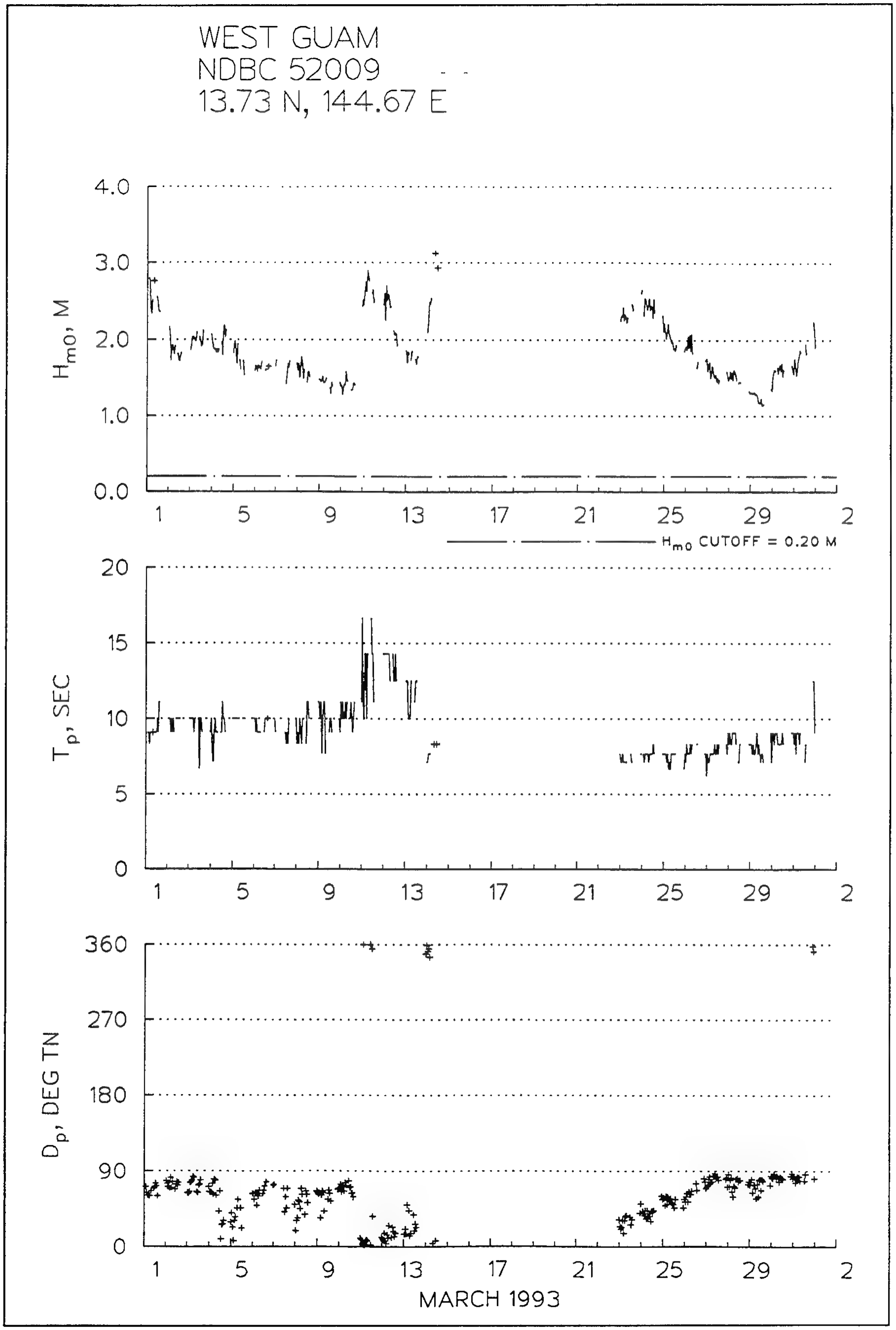

WEST GUAM
NDBC 52009
13.73 N, 144.67 E
8.0
6.0
4.0
2.0
0.0
H_{m0}, M
1
6
11
16
21
26
1
H_{mo} CUTOFF = 0.20 M
20
15
10
5
0
T_p, SEC
360
270
180
90
0
D_p, DEG TN
NOVEMBER 1992


WEST GUAM
NDBC 52009
13.73 N, 144.67 E
4.0
3.0
2.0
1.0
0.0
H_{m0}, M
1
5
9
13
17
21
25
29
2
H_{mo} CUTOFF = 0.20 M
20
15
10
5
0
T_p, SEC
360
270
180
90
0
D_p, DEG TN
OCTOBER 1992

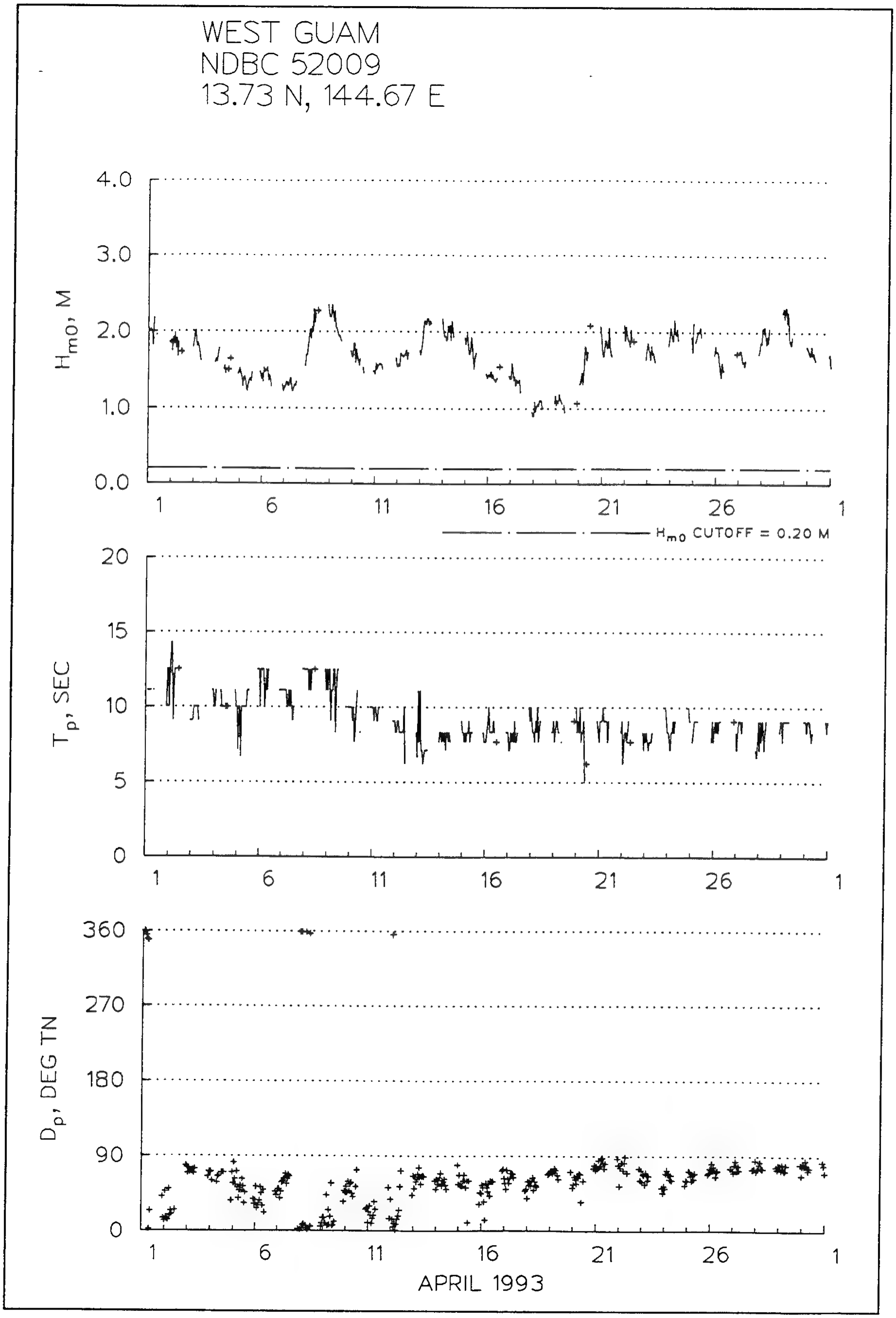

WEST GUAM
NDBC 52009
13.73 N, 144.67 E
4.0
3.0
2.0
1.0
0.0
H_{m0}, M
1
6
11
16
21
26
31
H_{mo} CUTOFF = 0.20 M
20
15
10
5
0
T_p, SEC
1
6
11
16
21
26
31
360
270
180
90
0
D_p, DEG TN
1
6
11
16
21
26
31
DECEMBER 1992

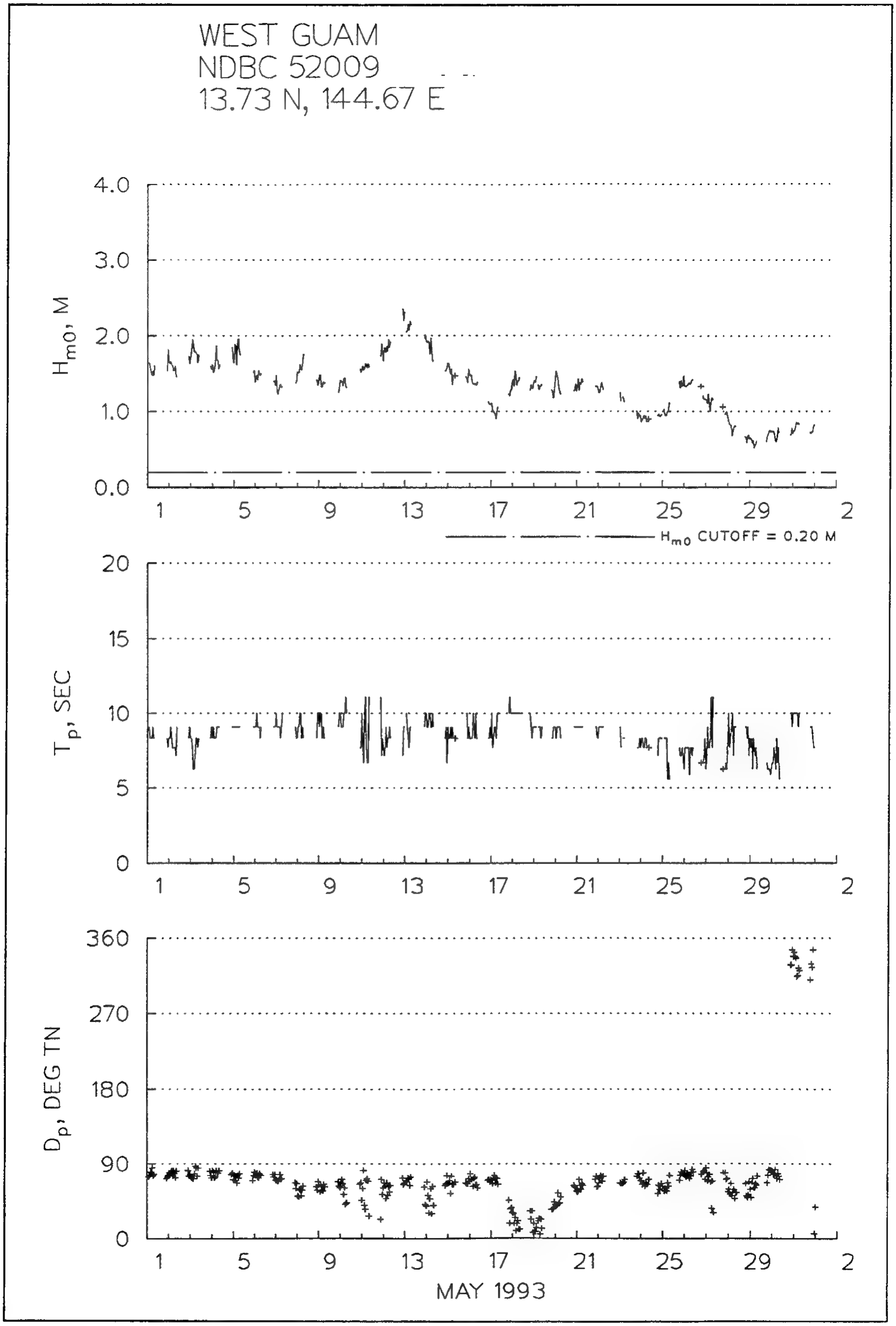

WEST GUAM
NDBC 52009
13.73 N, 144.67 E
4.0
3.0
2.0
1.0
0.0
H_{m0}, M
1
5
9
13
17
21
25
29
2
H_{mo} CUTOFF = 0.20 M
20
15
10
5
0
T_p, SEC
360
270
180
90
D_p, DEG TN
JANUARY 1993


WEST GUAM
NDBC 52009
13.73 N, 144.67 E
H_{m0}, M
4.0
3.0
2.0
1.0
0.0
1
5
9
13
17
21
25
1
H_{m0} CUTOFF = 0.20 M
T_p, SEC
20
15
10
5
0
D_p, DEG TN
360
270
180
90
0
FEBRUARY 1993

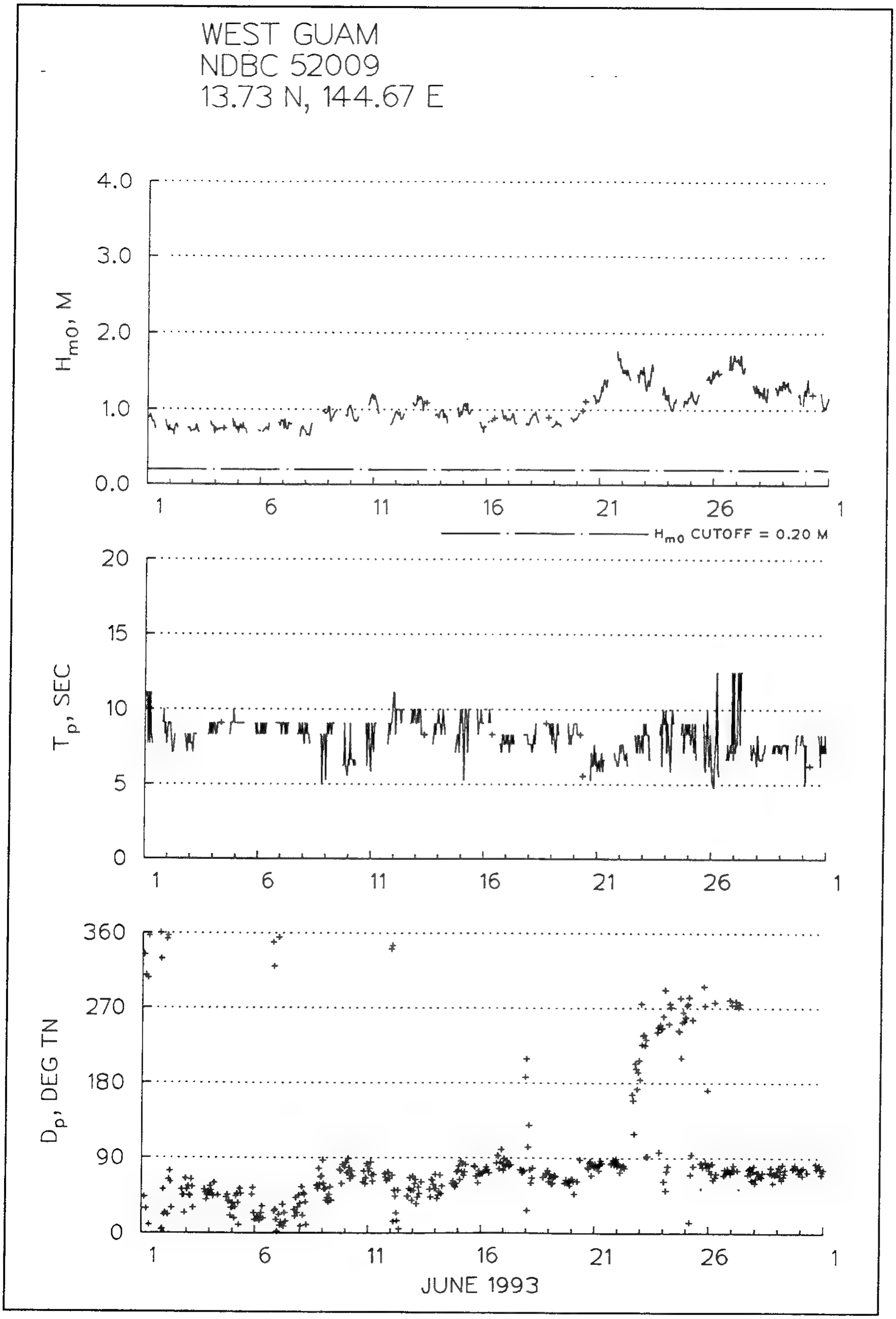


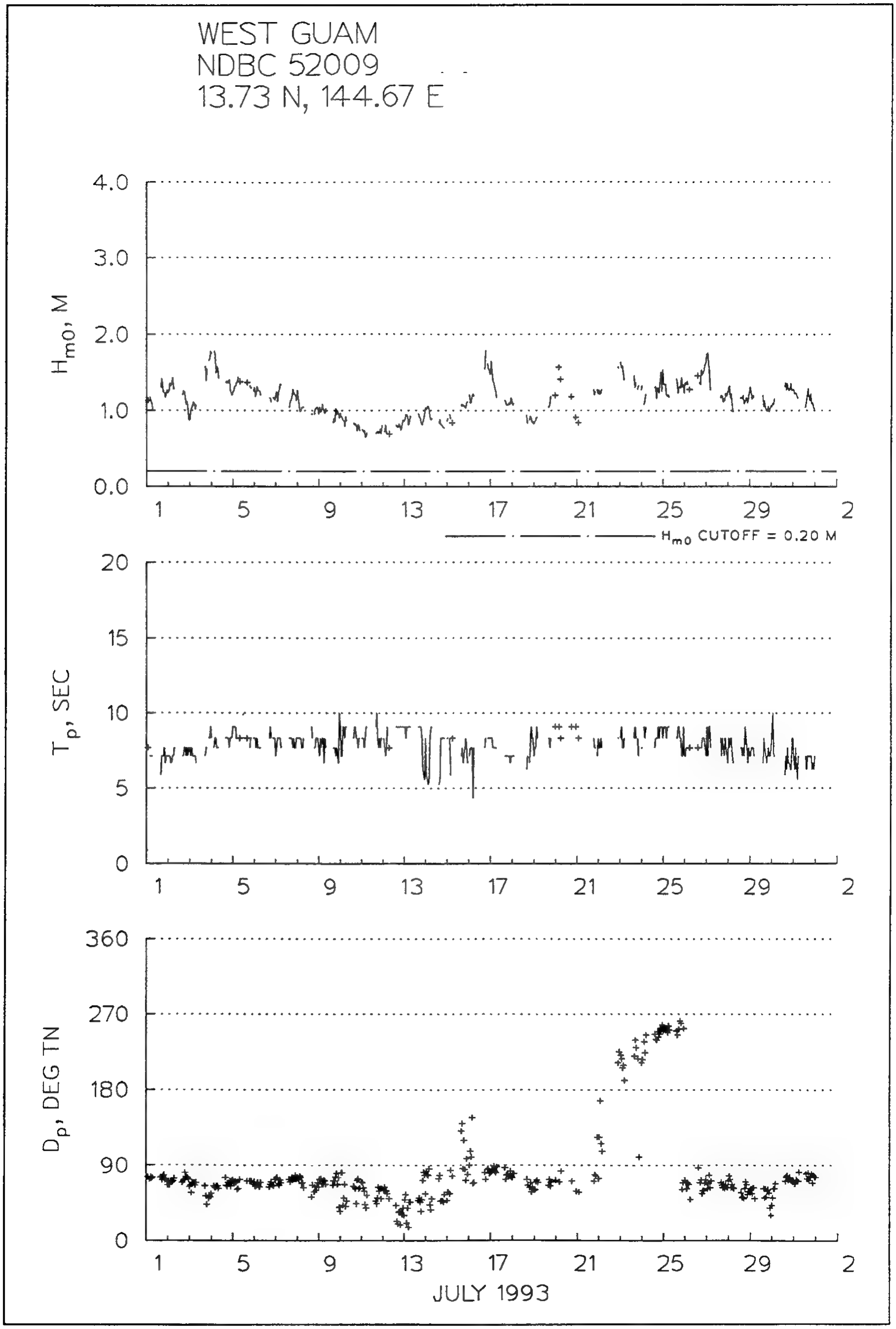
WEST GUAM
NDBC 52009
13.73 N, 144.67 E
4.0
3.0
2.0
1.0
0.0
H_{m0}, M
1
5
9
13
17
21
25
29
2
H_{m0} CUTOFF = 0.20 M
20
15
10
5
0
T_p, SEC
1
5
9
13
17
21
25
29
2
360
270
180
90
0
D_p, DEG TN
1
5
9
13
17
21
25
29
2
MARCH 1993

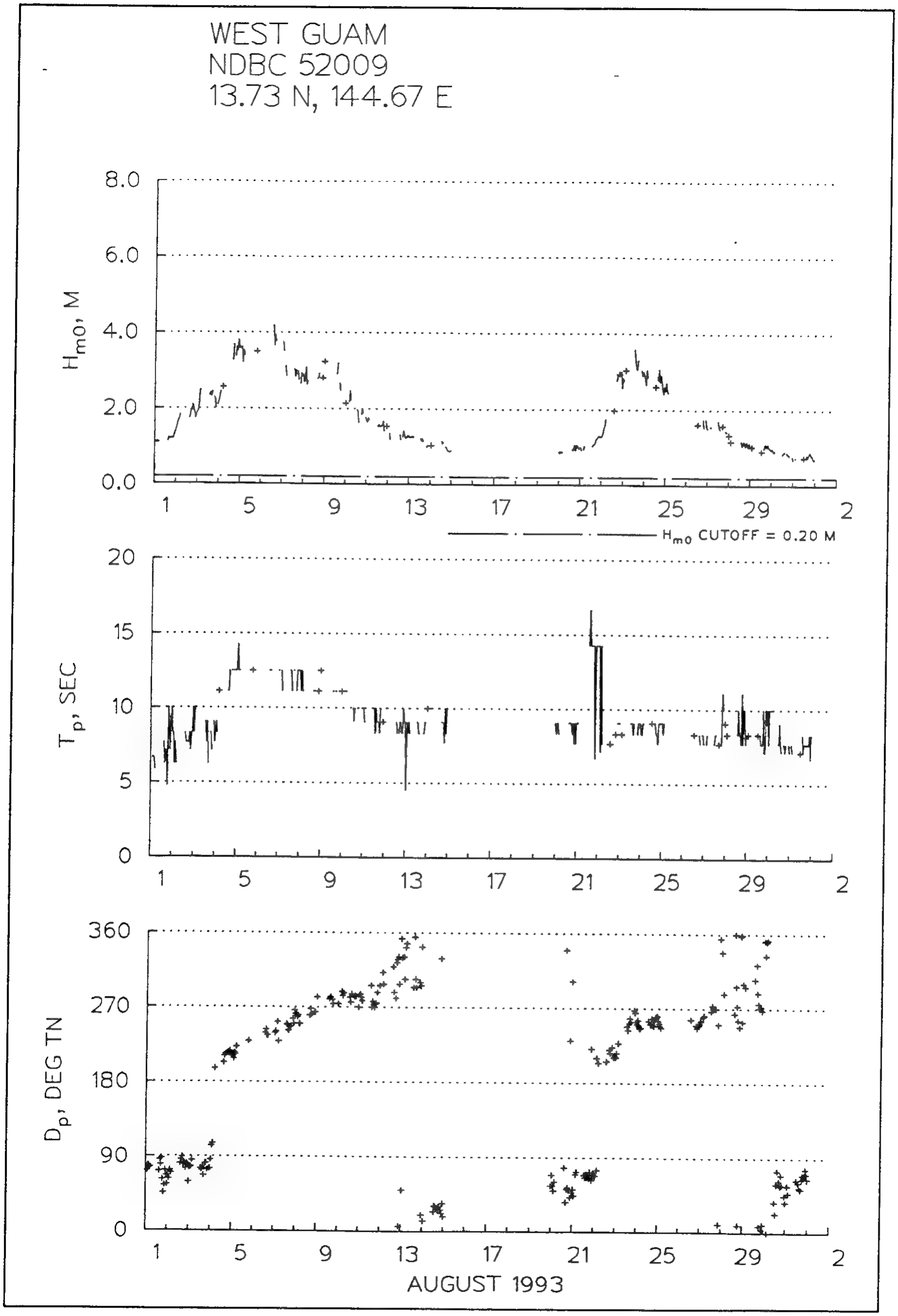

WEST GUAM
NDBC 52009
13.73 N, 144.67 E
4.0
3.0
2.0
1.0
0.0
H_{m0}, M
1
6
11
16
21
26
1
H_{mo} CUTOFF = 0.20 M
20
15
10
5
0
T_p, SEC
1
6
11
16
21
26
1
360
270
180
90
0
D_p, DEG TN
1
6
11
16
21
26
1
APRIL 1993

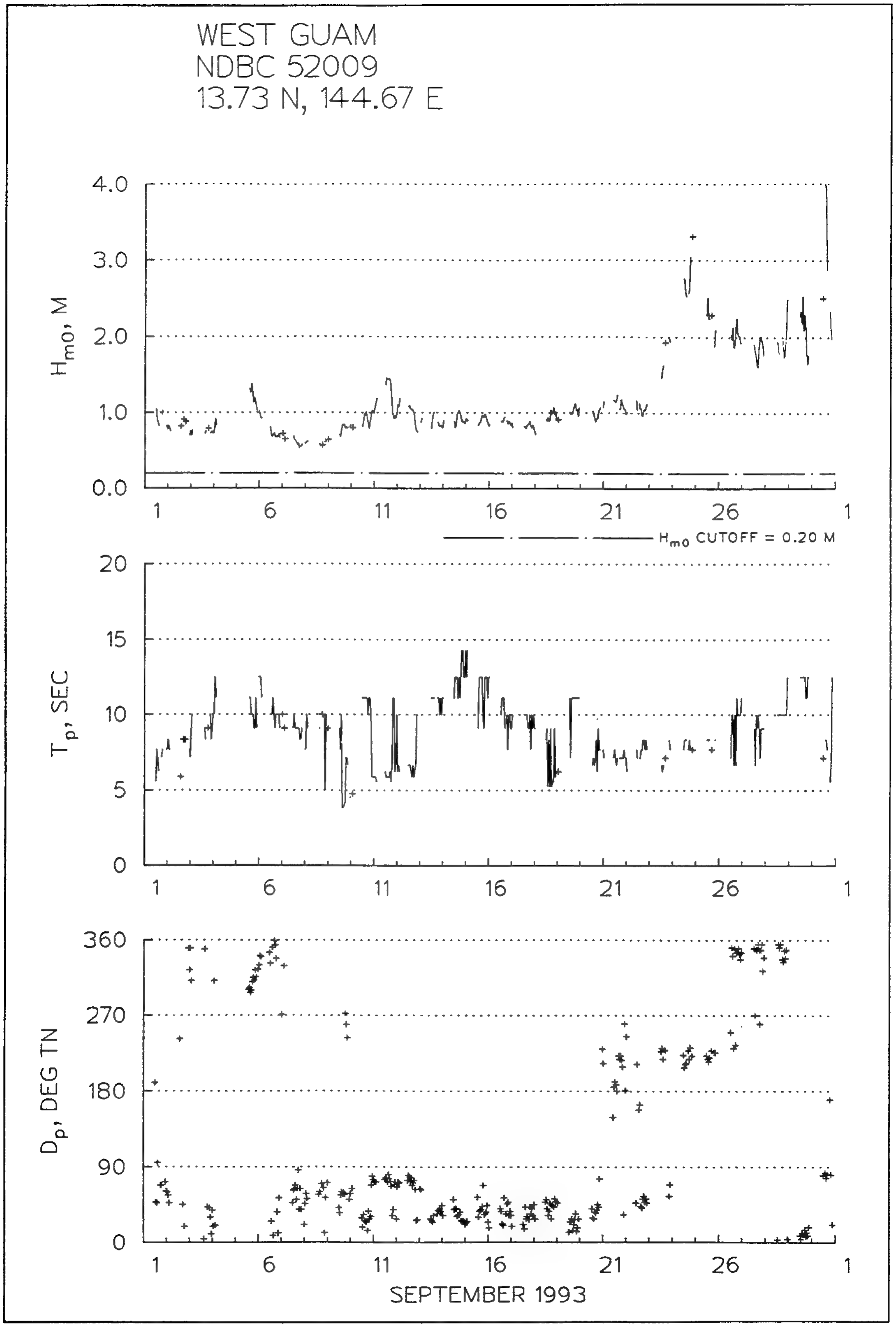


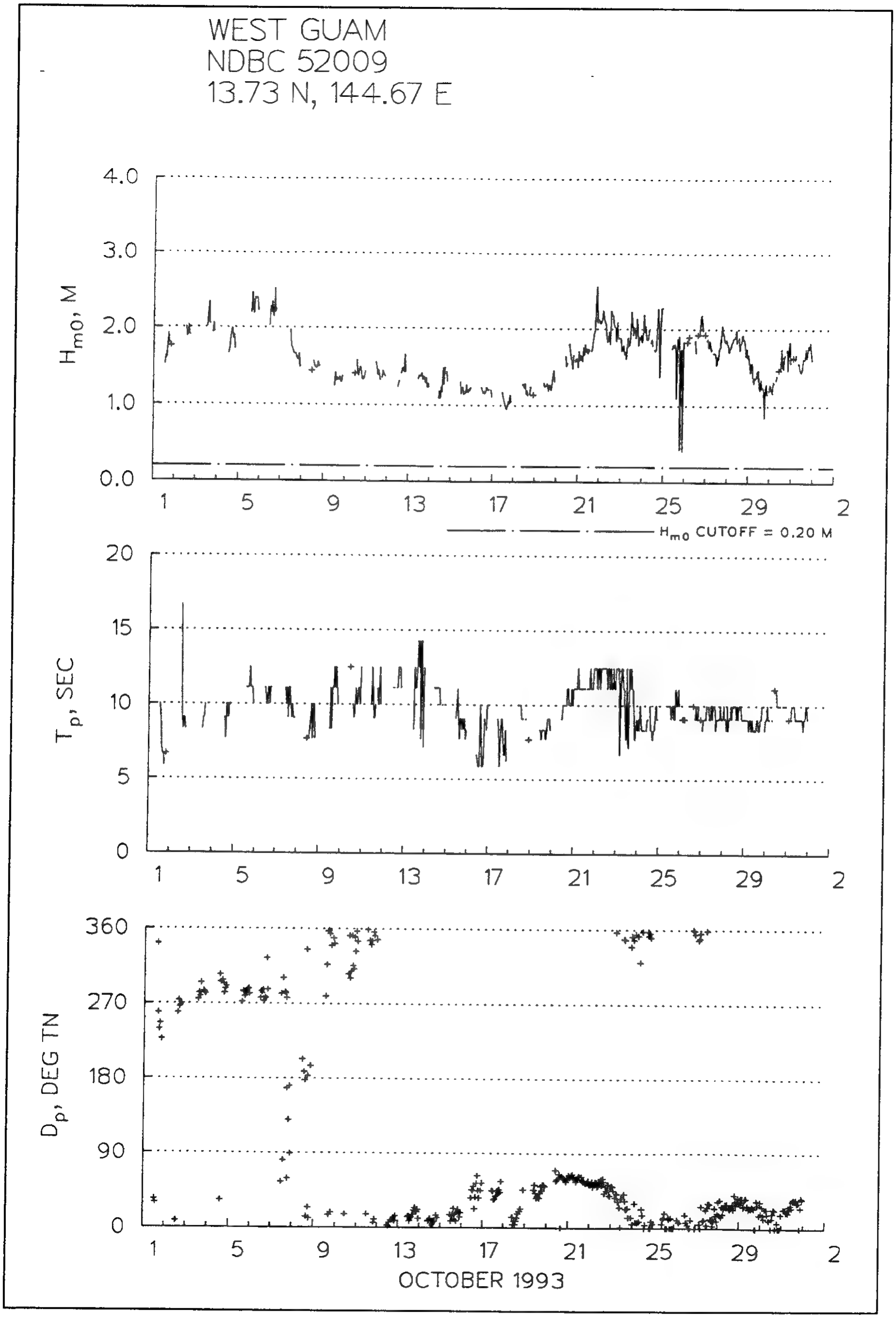
WEST GUAM
NDBC 52009
13.73 N, 144.67 E
4.0
3.0
2.0
1.0
0.0
H_{m0}, M
1
5
9
13
17
21
25
29
2
H_{m0} CUTOFF = 0.20 M
20
15
10
5
0
T_p, SEC
360
270
180
90
D_p, DEG TN
MAY 1993


WEST GUAM
NDBC 52009
13.73 N, 144.67 E
4.0
3.0
2.0
1.0
0.0
H_{m0}, M
1
6
11
16
21
26
1
H_{m0} CUTOFF = 0.20 M
20
15
10
5
0
T_p, SEC
1
6
11
16
21
26
1
360
270
180
90
0
D_p, DEG TN
1
6
11
16
21
26
1
JUNE 1993

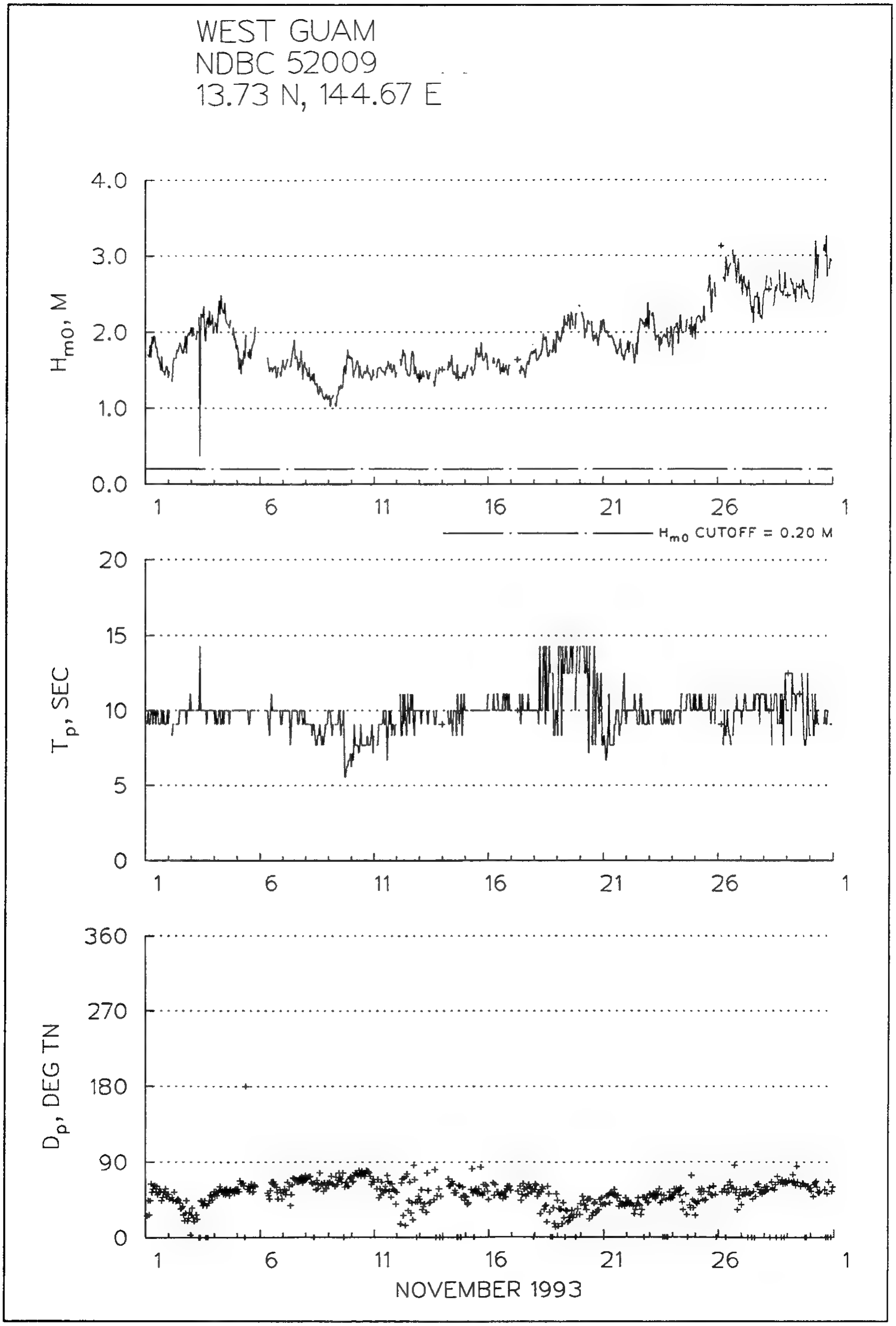

WEST GUAM
NDBC 52009
13.73 N, 144.67 E
4.0
3.0
2.0
1.0
0.0
H_{m0}, M
1
5
9
13
17
21
25
29
2
H_{m0} CUTOFF = 0.20 M
20
15
10
5
0
T_p, SEC
360
270
180
90
0
D_p, DEG TN
JULY 1993

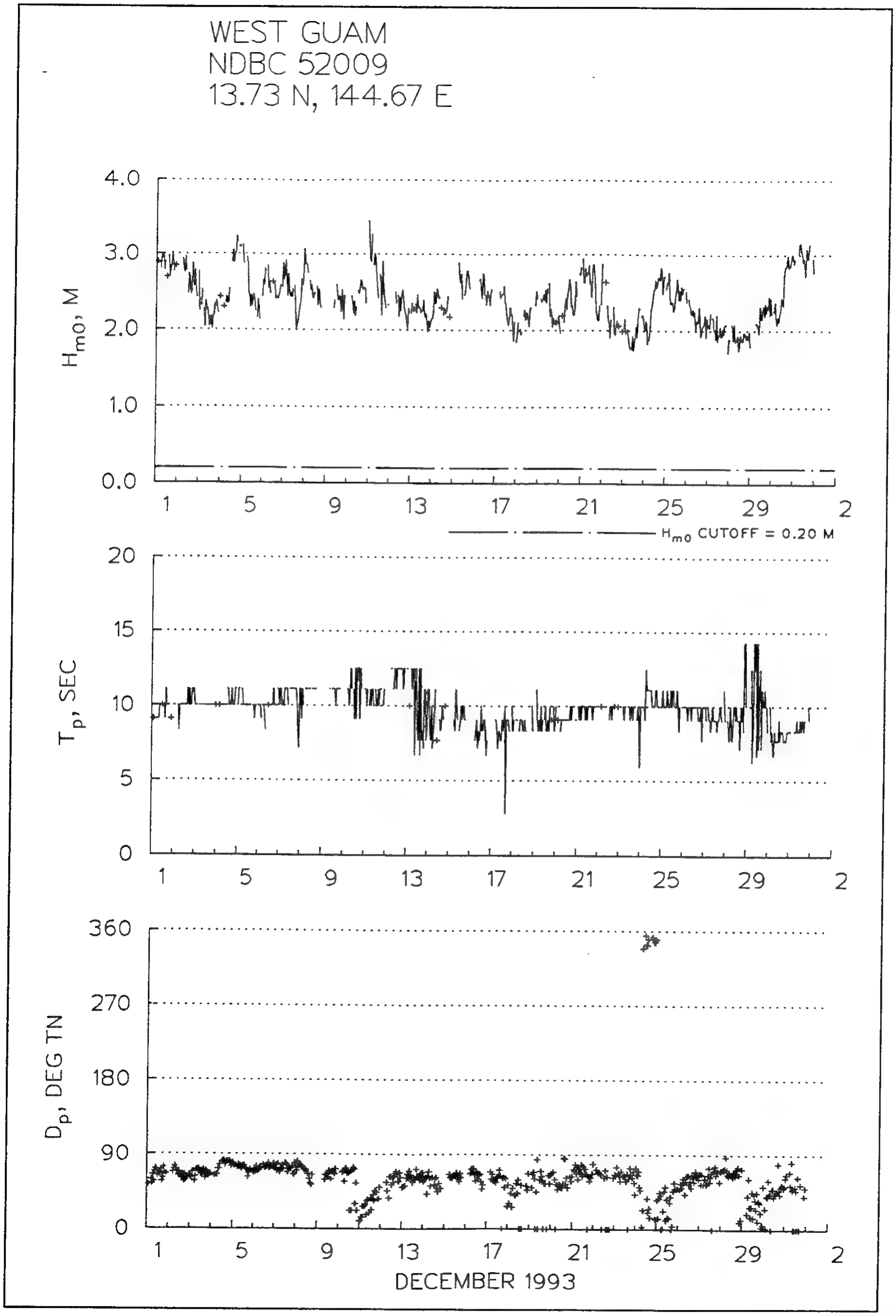

WEST GUAM
NDBC 52009
13.73 N, 144.67 E
8.0
6.0
4.0
2.0
0.0
H_{m0}, M
1
5
9
13
17
21
25
29
2
H_{mo} CUTOFF = 0.20 M
20
15
10
5
0
T_p, SEC
360
270
180
90
D_p, DEG TN
AUGUST 1993

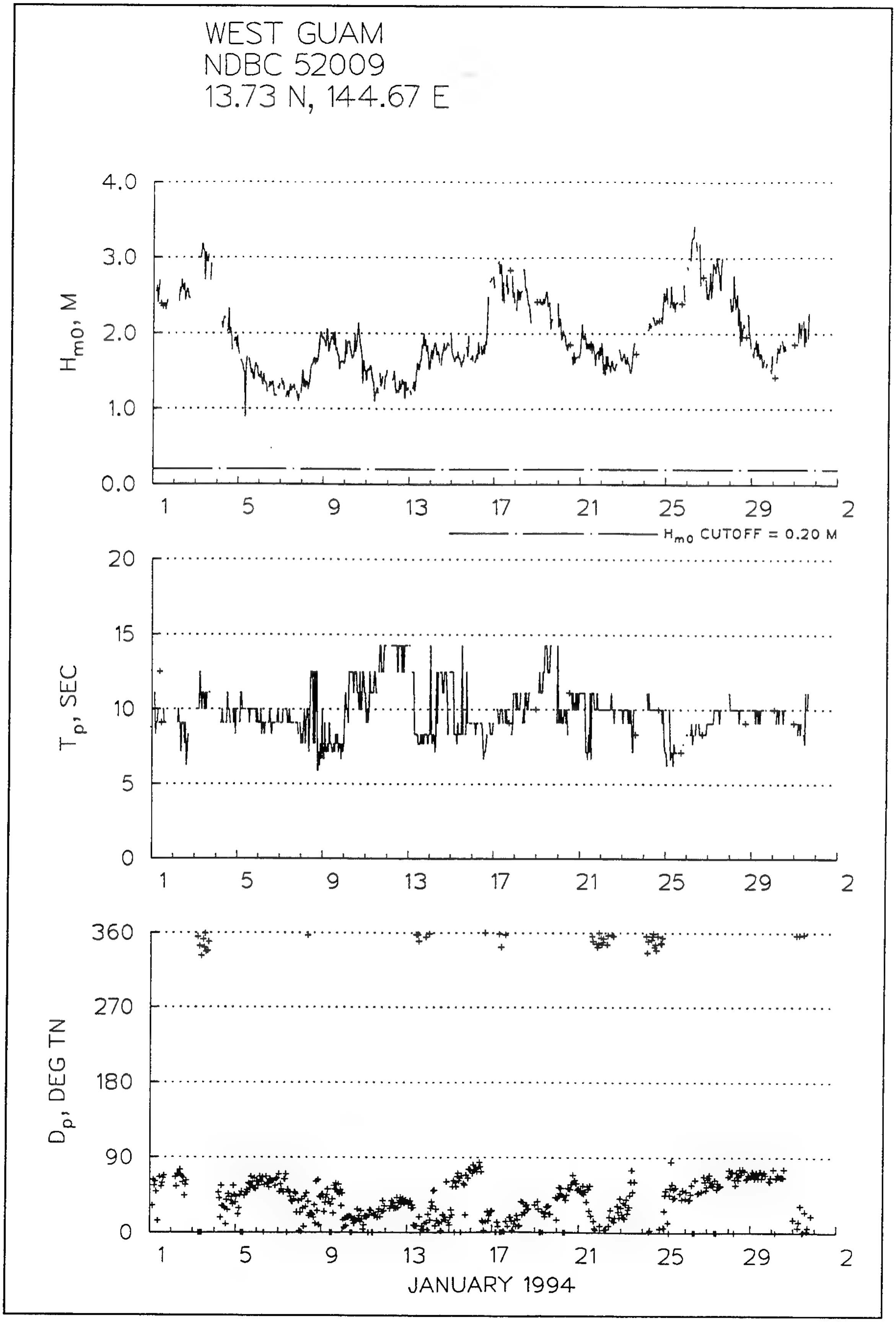

WEST GUAM
NDBC 52009
13.73 N, 144.67 E
4.0
3.0
2.0
1.0
0.0
H_{m0}, M
1
6
11
16
21
26
1
H_{m0} CUTOFF = 0.20 M
20
15
10
5
0
T_p, SEC
360
270
180
90
0
D_p, DEG TN
SEPTEMBER 1993

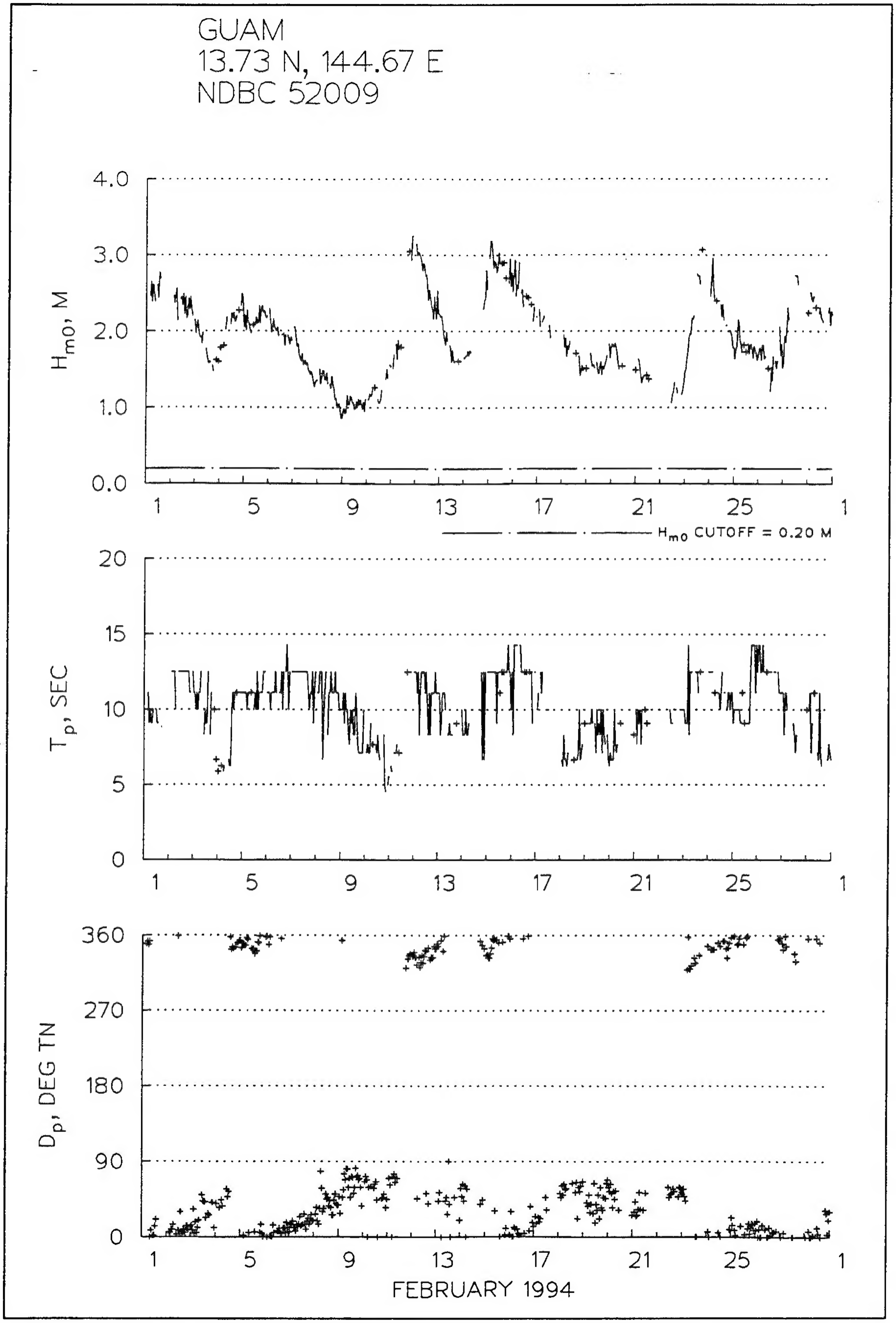


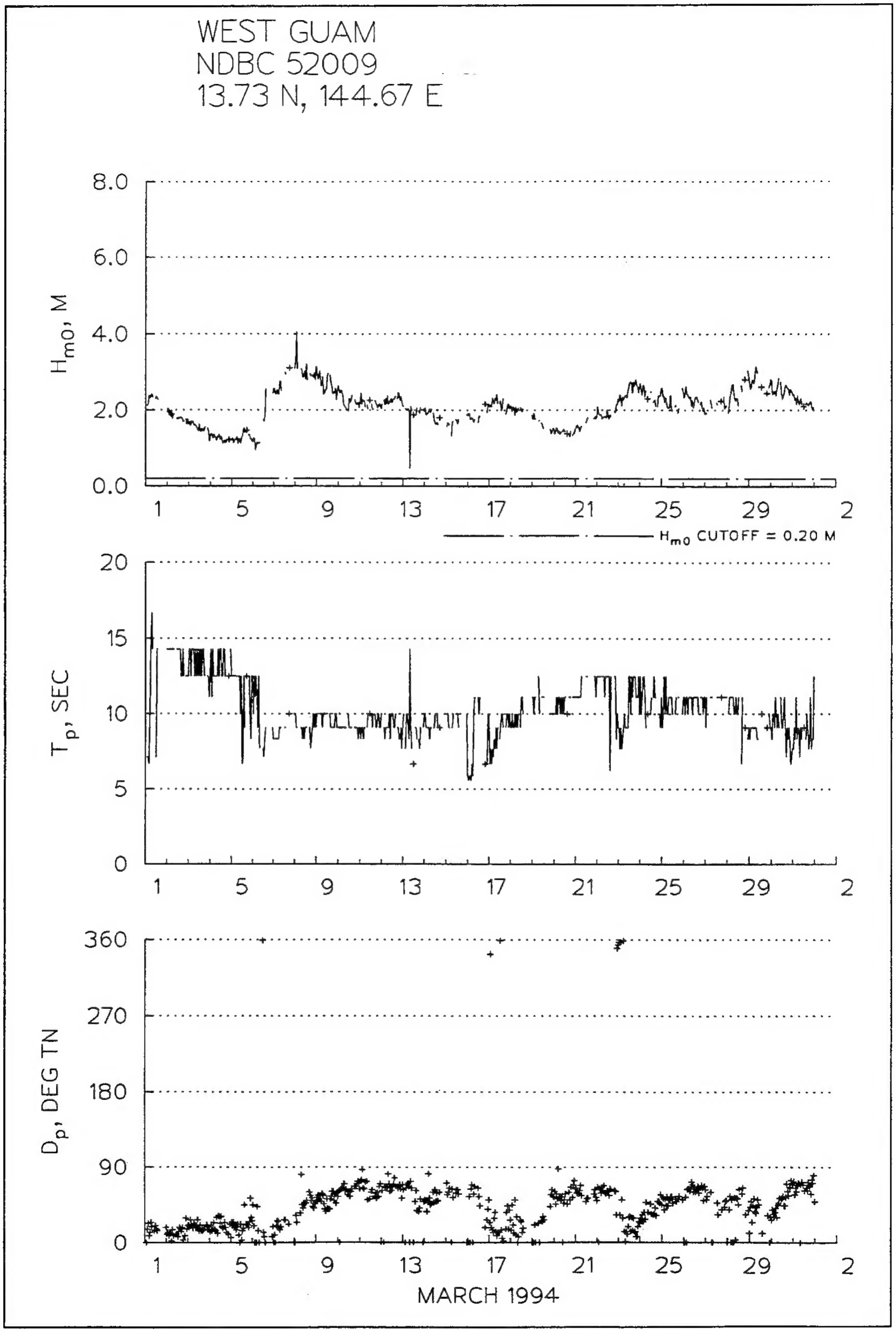
WEST GUAM
NDBC 52009
13.73 N, 144.67 E
4.0
3.0
2.0
1.0
0.0
H_{m0}, M
1
5
9
13
17
21
25
29
2
H_{m0} CUTOFF = 0.20 M
20
15
10
5
0
T_p, SEC
360
270
180
90
0
D_p, DEG TN
OCTOBER 1993


WEST GUAM
NDBC 52009
13.73 N, 144.67 E
4.0
3.0
2.0
1.0
0.0
H_{m0}, M
1
6
11
16
21
26
1
H_{m0} CUTOFF = 0.20 M
20
15
10
5
0
T_p, SEC
360
270
180
90
0
D_p, DEG TN
NOVEMBER 1993

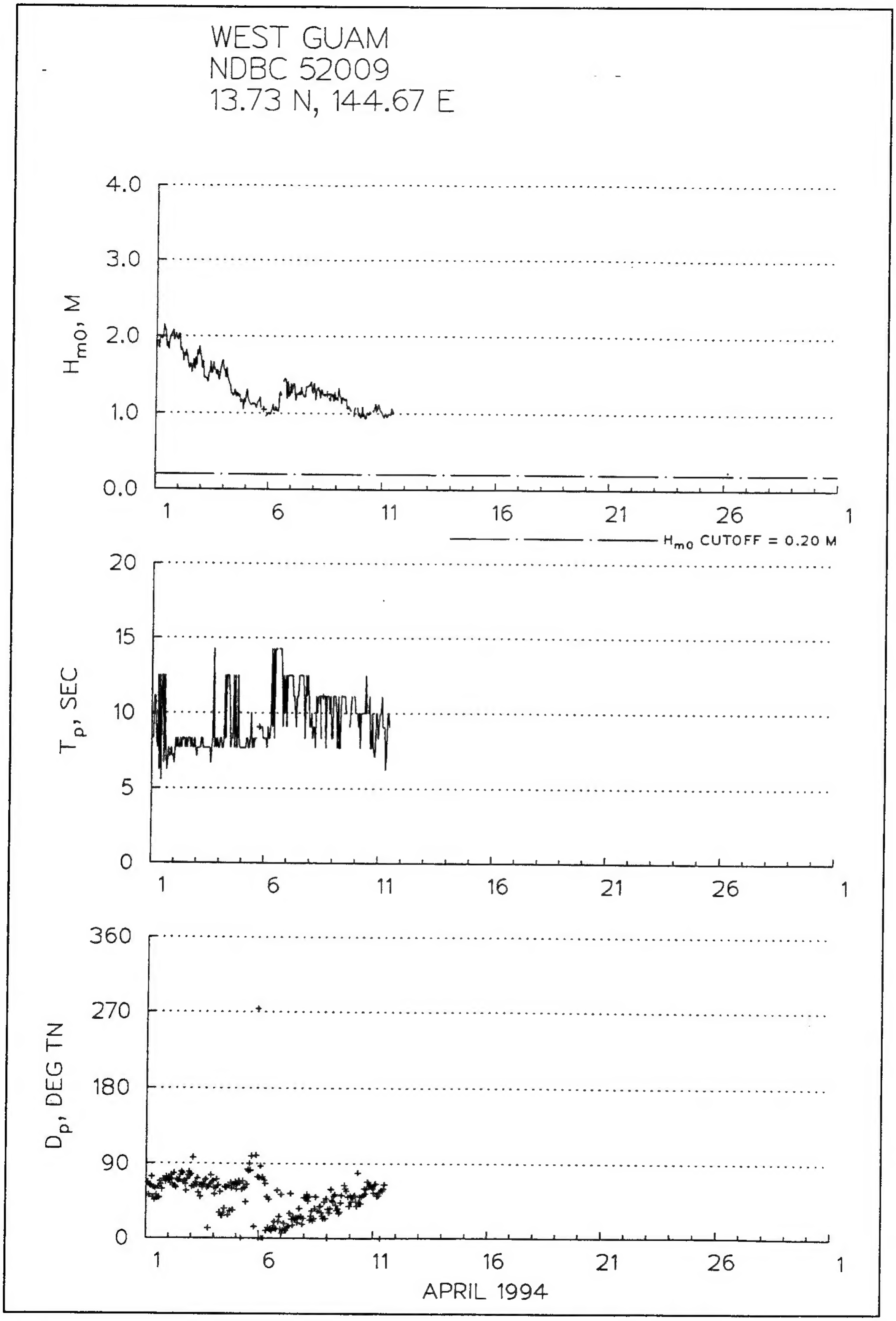

WEST GUAM
NDBC 52009
13.73 N, 144.67 E
4.0
3.0
2.0
1.0
0.0
H_{m0}, M
1 5 9 13 17 21 25 29 2
H_{mo} CUTOFF = 0.20 M
20
15
10
5
0
T_p, SEC
1 5 9 13 17 21 25 29 2
360
270
180
90
0
D_p, DEG TN
1 5 9 13 17 21 25 29 2
DECEMBER 1993


WEST GUAM
NDBC 52009
13.73 N, 144.67 E
4.0
3.0
2.0
1.0
0.0
H_{m0}, M
1
5
9
13
17
21
25
29
2
H_{mo} CUTOFF = 0.20 M
20
15
10
5
0
T_p, SEC
360
270
180
90
0
D_p, DEG TN
JANUARY 1994


GUAM
13.73 N, 144.67 E
NDBC 52009
H_{m0}, M
4.0
3.0
2.0
1.0
0.0
1
5
9
13
17
21
25
1
H_{m0} CUTOFF = 0.20 M
T_p, SEC
20
15
10
5
0
D_p, DEG TN
360
270
180
90
0
FEBRUARY 1994



WEST GUAM
NDBC 52009
13.73 N, 144.67 E
8.0
6.0
4.0
2.0
0.0
H_{m0}, M
1
5
9
13
17
21
25
29
2
H_{mo} CUTOFF = 0.20 M
20
15
10
5
0
T_p, SEC
360
270
180
90
0
D_p, DEG TN
MARCH 1994


WEST GUAM
NDBC 52009
13.73 N, 144.67 E
4.0
3.0
2.0
1.0
0.0
H_{m0}, M
1
6
11
16
21
26
1
H_{mo} CUTOFF = 0.20 M
20
15
10
5
0
T_p, SEC
360
270
180
90
D_p, DEG TN
APRIL 1994

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
December 1997

3. REPORT TYPE AND DATES COVERED
Final report

4. TITLE AND SUBTITLE
Results of Monitoring Study of Agat Harbor, Guam

5. FUNDING NUMBERS

6. AUTHOR(S)
David D. McGehee, Stanley Boc

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Engineer Waterways Experiment Station, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199; U.S. Army Engineer Division, Pacific Ocean, Bldg. 230, Fort Shafter, HI 96858-5440

8. PERFORMING ORGANIZATION REPORT NUMBER
Technical Report CHL-97-22

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Corps of Engineers
Washington, DC 20314-1000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Agat Harbor, Guam, was selected for monitoring under the Monitoring of Coastal Projects Program, which is sponsored by Headquarters, U.S. Army Corps of Engineers. During a 3-year observation period, the following data were collected:

a. Directional energy spectra and surface winds from an offshore site.
b. Energy spectra at several locations on a shore-normal transect across the reef flat.
c. Wave conditions and water elevations at the structure and harbor response during large wave events.
d. Directional energy spectra at the outer boundary of the model and at several sites within the harbor.
e. Energy spectra at the outer and inner ends of the channel.
f. Periodic site inspections and aerial photographs of the harbor and surroundings.

Most of the quantitative objectives of the study were not met because of the lack of measured data during high-energy events. However, observations have resulted in valuable qualitative information that should be considered when planning or designing projects in a similar environment.

14. SUBJECT TERMS

Breakwater	Harbor	Transformation
Cnoidal	Reefs	Typhoon
Coral	Surge	Waves

15. NUMBER OF PAGES
180

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED		